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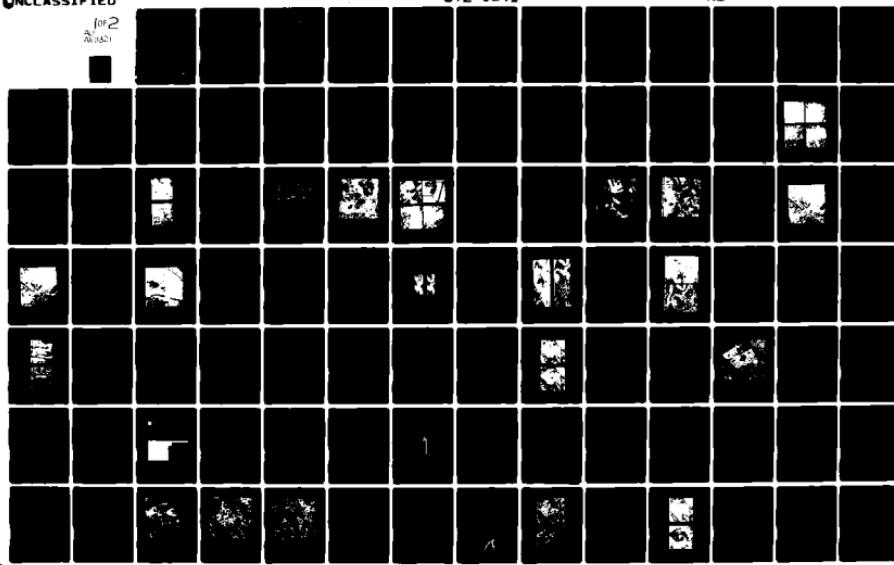
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INTERACTIVE DIGITAL IMAGE PROCESSING FOR TERRAIN DATA EXTRACTION

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4701 Forbes Boulevard
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November, 1980

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addressed in varying degrees of depth in the study. Interactive digital techniques are developed for vegetation/land cover boundary extraction, and for the extraction of several forest related data elements such as percent canopy closure, number of stems per hectare, tree crown diameter, number of trees per hectare in each stem diameter class, and others. The extraction techniques are developed using an existing general-purpose, interactive digital image analysis system - the General Electric DIAL (Digital Image Analysis Laboratory). Results are compared in two cases to those achieved via existing manual analysis procedures. While the interactive digital extraction techniques exhibit a promising potential, some technical problems remain. Further development, testing and evaluation are warranted using greater variety of test imagery, including radar and thermal imagery.

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SUMMARY

A 12-month experimental study has been performed to investigate the feasibility and utility of man-machine interactive digital image processing techniques when applied to the extraction of terrain analysis data from aerial imagery. The study focuses primarily on the extraction of vegetation data elements from digitized panchromatic photography, with a small amount of attention given to thermal infrared and side-looking radar imagery. Because of limited availability of suitable panchromatic photography, selected channels of digital multispectral scanner data also were used in portions of the study.

Of thirteen vegetation data elements listed in the USAETL Terrain Analysis Procedural Guide for Vegetation, eight are addressed in this investigation in varying degrees of depth. Interactive digital techniques are developed for vegetation/land cover boundary extraction, and for the extraction of several forest-related data elements. In particular, for the forest-related elements, three digital themes (binary maps) are developed from digitized panchromatic photography which make it possible for an automated operation to produce the following: Percent canopy closure; Stems per hectare; Crown diameter; Stem diameter; Stems per hectare per diameter class; and Stem spacing. Best results are achieved with a spatial resolution of approximately three feet in the input digital image. To extract vegetation/land-cover boundaries from digitized panchromatic photography, other procedures are developed which are keyed to the use of a digital texture image derived from the input image. In some cases the use of supplementary digital thermal imagery is desirable or necessary. The extraction is most effective when the spatial resolution of the input digital imagery is in the range of 8 to 20 feet.

The extraction techniques are developed and tested using an existing general-purpose, interactive digital image analysis system - the General Electric DIAL (Digital Image Analysis Laboratory). Results are compared in two cases to those achieved via existing manual analysis procedures. While the interactive digital extraction techniques exhibit a promising potential, some

technical problems remain. Further development, testing and evaluation is warranted using a greater variety of test imagery, including radar and thermal imagery.

PREFACE

This document is generated under Contract DAAK70-79-C-0153 for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060 by the General Electric Company, Space Division, Beltsville, Maryland. The Contracting Officer's Representative was Mr. Lawrence P. Murphy.

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INTERACTIVE DIGITAL IMAGE PROCESSING FOR TERRAIN DATA EXTRACTION

I. INTRODUCTION

A. Background

Terrain analysis is the process of analyzing a geographical area to determine the effect of the natural and man-made features on military operations. Terrain is defined as a portion of the earth's surface, including man-made and natural features. The primary product of a terrain analysis, for purposes of this study, is a special-purpose map.

Specific procedures for manual extraction of terrain analysis data are identified in a compilation of seventeen procedural guides prepared (or in preparation) by USAETL. These guides highlight the factor overlay concept. Under this concept data are extracted from various source materials and recorded on factor overlays and supporting data tables. Factor overlays are registered to standard military topographic maps. Separate overlays and tables are prepared for each map sheet for each major terrain subject or data field, e.g. surface materials, surface configuration, vegetation, drainage and roads. Factor overlays are used in various combinations to generate factor complex maps. Data from factor complex maps, coupled with analytical models, enable the production of special-purpose products such as cross-country movement graphics, fields of fire, IPB (Intelligence Preparation of the Battlefield) graphics, etc.

Recent developments in computer manipulation of digital elevation data have made it possible to produce, using a minicomputer, such products as line-of-sight diagrams, slope maps and oblique views. Thus it appears reasonable to consider a computer-based system for use in preparation of terrain analysis products in a field environment.

B. Objective

The objective of the investigation reported here has been to perform an experimental study of man-machine interactive digital image processing techniques as applied to the extraction of terrain analysis data from aerial imagery.

C. Scope

The permissible scope of the study involved investigating the extraction of terrain data in the following categories and in the order listed:

- Vegetation
- Water Resources
- Roads and Related Structures
- Rock Types
- Surface Configuration
- Surface Materials

The study reported here, however, has been concentrated solely on the extraction of vegetation data. Further, although a variety of input data must normally be considered in terrain analysis, this study has been concerned only with aerial imagery and the data which can be derived from it.

D. Vegetation Data Elements

In this study, the vegetation elements considered were selected from the following list:*

1. Map unit identification/vegetation boundaries
2. Mean height to top of canopy
3. Percent canopy closure
4. Number of stems per hectare
5. Tree crown diameter
6. Mean stem diameter
7. Number of trees in each stem diameter class per hectare
8. Stem spacing
9. Species identification, seasonality, and distribution
10. Ground cover type, percent of cover, and height
11. Litter type and depth
12. Mean height to lowest branches
13. A representative transect.

The first eight elements in the above list were addressed in the study, although not all with equal weight.

*Contained in the USAETL Purchase Description for this study, and in the USAETL "Terrain Analysis Procedural Guide for Vegetation", Jeffrey A. Messmore, Theodore C. Vogel and Alexander R. Pearson, (ETL-0178, March 1979, AD-A068 7150.

E. General Study Approach

The following sequence outlines the principal steps which were followed in the investigation:

1. Review existing procedures for terrain data extraction as described in USAETL procedural guides, particularly the guide for vegetation.
2. Conceive alternative interactive digital image analysis procedures.
3. Select imagery to be used in the development and evaluation of the new procedures.
4. Test the new procedures using an appropriate interactive digital image analysis facility as a test bed. For this investigation the test bed has been the General Electric Digital Image Analysis Laboratory (DIAL) facility in Beltsville, Maryland.
5. Assess results, and iterate steps 2 and 4 as appropriate.
6. Where feasible, compare results with performance achieved by USAETL using existing procedures.

The General Electric DIAL facility, used as the test bed, operates in both an Interactive and a Batch mode. In this study only the Interactive mode was employed. Interactive operations are implemented primarily via special-purpose hardware in DIAL's Image Analyzer, with a PDP 11/35 mini-computer used as a Process Controller. An extensive amount of DIAL applications software exists, and this study has drawn heavily on that available software to accomplish various image processing and terrain data extraction operations. Since DIAL is a flexible, general-purpose image analysis facility, however, the available DIAL hardware and software does not necessarily represent an optimum system configuration for the operations performed in this (or any) study.

Figure 1 depicts the GE DIAL interactive configuration, plus the scope of inputs and outputs for this investigation. Principal imagery input in this study is in the form of black-and-white transparencies. These are

scanned and digitized in the GE DIAL facility for subsequent interactive digital analysis (also in DIAL). The digitized image has a maximum of 512 x 512 pixels, and 8-bit gray-level quantization. For cases where this resolution is not adequate, a transparency digitizing service is employed.* Aircraft electronic scanner digital image data also has been used in the investigation. For these cases the input to the GE DIAL system is via magnetic tape.

A variety of GE DIAL output products (imagery, graphics, data) are available as shown in Figure 1. For this investigation the principal output products are Digital Image Recording on black-and-white film, Annotated Thematic Maps via the Printer, and Graphics Terminal HardCopier output.

*In this study, this service was provided by USAETL.

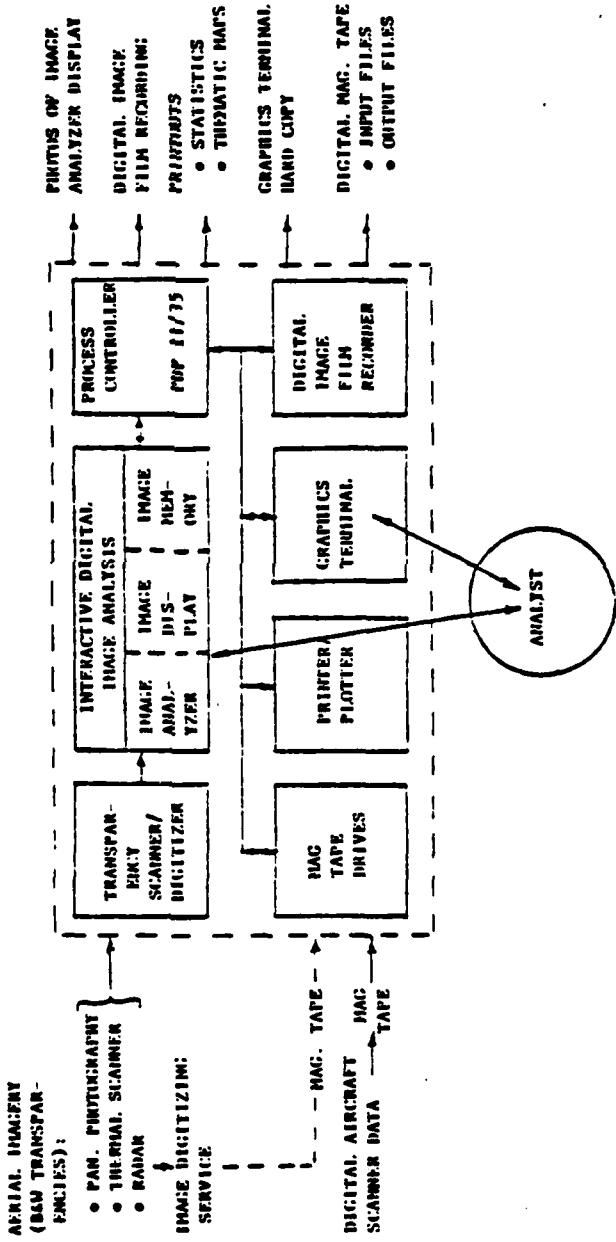


Figure 1. Utilization of General Electric DIAL for Terrain Data Extraction.

II. IMAGERY FOR USE IN EXTRACTION TECHNIQUE DEVELOPMENT

A. Imagery Selection/Evaluation Approach

Aerial imagery considered for use in this study includes panchromatic photography, side-looking radar imagery and thermal infrared imagery - all in transparency form. The selected imagery then is digitized so that digital analysis techniques, which are the focus of this study, may be investigated. As the imagery selection process evolved, it became desirable to include digital multispectral scanner data with the initial three imagery types.

At the outset, the intent was to search for sets of imagery where each set consisted of photographic, radar and thermal recordings of the same scene acquired at essentially the same time. This proved to be a difficult goal within the time and resources for the study. A few sets were found, but invariably one or more of the images in the set was unacceptable because of poor resolution, poor contrast or inappropriate scene content. The selection process then was concentrated on a search for suitable frames of imagery of any of the three types. As noted previously, this was expanded to include some digital multispectral scanner data on magnetic tape. Here it was possible to have some visible region and thermal infrared data for the same scenes. This offers the possibility to simulate the use of a panchromatic photograph and a thermal image set.

Factors considered in the imagery selection include:

- Scene content (should contain woodland, grassland, marsh, etc.)
- Resolution (some imagery should have 2-3 foot resolution, or better)
- Adequate contrast among the land-cover categories
- Absence of clouds, cloud shadows and haze
- Uniformity of scene feature brightness levels across the image
- Near-vertical view of the scene
- General quality of the transparency (e.g., absence of scratches, etc.)

The imagery initially selected was subjected to a preliminary digital analysis for the extraction of land-cover classes and tree crowns. (The techniques used are those described in subsequent sections of this report). In those cases where the preliminary results were poor or marginal, the imagery was rejected for further use. It should be pointed out that when it was realized that suitable sets of imagery were not available for this study, the preliminary analysis and evaluation effort became focused on the potential of individual frames of imagery. Thus, a thermal infrared transparency was evaluated with regard to its potential for enabling complete vegetation/land cover boundary extraction. The potential of the thermal infrared transparency as a supplement to panchromatic photography was not considered heavily in the preliminary analysis.

For radar image transparencies, the evaluation approach was similar. That is, radar imagery was not evaluated for its potential as a supplement to panchromatic photography, but only for its potential when used alone. This implies that a more thorough evaluation of candidate imagery is desirable in the future.

B. Imagery Considered for Use in the Study

Table 1 lists all imagery considered for use in the study.

C. Side-Looking Radar Imagery

Seven 512 x 512 pixel subscenes were digitized in the GE DIAL facility from 2 cm x 2 cm areas on three radar positive transparencies. Scotia/Schenectady/Albany; Stockbridge; and Cape Henlopen. The estimated radar resolution in the imagery is 15-30 feet (or poorer, in some cases), while the digitizing resolution is about equal or better than this. Thus, the digitizing should not appreciably degrade the image resolution in the radar recordings. It was noted, however, that the images were noisy and that scene feature intensity levels were not uniform over the image.

Figure 2 shows four digitized subscenes from the radar imagery. The Stockbridge subscene appears at upper left. It is shown again at the upper right for conditions in which photographic enlargement was employed

Table 1. Imagery Considered for Use in the Study

SCENE AND SOURCE	IMAGE TYPE* AND QUANTITY	APPROX. IMAGE SCALE	IMAGE SIZE	OTHER INFORMATION
Scotia, N.Y. Naval Depot USAETL	Panchro. Photog. (2) Thermal IR (1) Radar (1)	1:20,000 1:10,000 1:112,000	9x9 4x12 2x9	Stereo pair
Stockbridge, N.Y. USAETL	Panchro. Photog. (2) Thermal IR (1) Radar (1) Radar (1)	1:10,000 1:6,000 1:180,000 1:25,000	9x9 4x13 2x13 9x9	Stereo pair GE enlargement from above
Schenectady, N.Y. Airfield Area USAETL	Panchro. Photog. (2) Thermal IR (1) Radar (1)	1:20,000 1:10,000 1:112,000	9x9 4x11 4x12	Stereo pair
Cape Henlopen, Delaware USAETL	Color IR Photog. (1) " " " (1) " " " (2) Panchro. Photog. (2) " " (1) Thermal IR (1) Radar (1)	1:60,000 1:21,000 1:12,000 1:40,000 1:20,000 1:135,000 1:410,000	9x9 9x9 9x9 9x9 9x9 9x9 4x6	Negative transparency Negative transparency
Fort Belvoir/Woodbridge, Va. USAETL	Panchro. Photog. (5) Digitized 5"x5" (3) subscenes from above	1:10,000 1610x1610 pixels, each 2.7 ft. x 2.7 ft. for each subscene	9x9	Stereo 2 subscenes are stereo pair

* Positive transparency unless noted otherwise

Table 1. Imagery Considered for Use in the Study (Continued)

SCENE AND SOURCE	IMAGE TYPE AND QUANTITY	APPROX. IMAGE SCALE	IMAGE SIZE	OTHER INFORMATION
Clarion County, Pa. GE	Color Photog. (10) Color Photog. (5) Color IR Photog. (1) " " " " " " " " " " " " " " " " " " Panchro. Photog. (4) " " 11 Channel Digital Scanner Data	1:12,000 1:12,000 1:39,000 1:18,300 1:4,200 1:4,200 1:6,000 1:4,200 1:6,000	9x9 9x9 9x9 9x9 9x9 9x9 9x9 9x9 9x9	Prints 10/30/79 Prints 9/29/78 Print 5/17/79 " " " " " " " " Prints, Negs. 5/17/79 Prints 9/29/79 20K ft. alt. 5/17/79 10K ft. alt. 5/17/79 5K ft. alt. 5/17/79 11/77
Clarion County, Pa.	11 Channel Digital Scanner Data	2000 lines of 700 pixels each; pixel size 44 ft.x36 ft.		
West Central Florida GE	11 Channel Digital Scanner Data	2000 lines of 700 pixels each; Pixel size 22 ft.x18 ft.		
		1800 lines of 700 pixels each; Pixel size 11 ft.8 ft.		
		5 subscenes, 512x 512 pixels; Pixel size 5 ft.x5 ft.		



Figure 2. Digitized Radar Images

before digitizing. The Cape Henlopen subscene appears at the lower left, and exhibits less resolution than the other images. At lower right is the Schenectady airfield subscene.

In Figure 3, at the top, the digitized subscene for the Albany airfield area is shown. At the bottom, for comparison, the original radar transparency was photographically enlarged to present the same subscene. Of the available radar images, the Albany airfield subscene appeared to have the most useful scene content and resolution for purposes of this study. Accordingly, preliminary vegetation classification was attempted using the digital image and a smoothed texture version of that image. (See a subsequent section of this report for the analysis procedure).

Two vegetation/land cover themes were extracted in the preliminary analysis of the Albany airfield digital image: Grassland plus Blacktop Runways (Figure 4); and Forest (Figure 5). These themes are "noisy" and have many omission errors. For purposes of producing vegetation factor overlays, these results are considered unacceptable. The preliminary analysis did not, however, address the potential of the digital radar image for extraction of forest-related vegetation elements. That should be examined in the future.

D. Thermal Infrared Imagery

Seven 512 x 512 pixel subscenes were digitized in the GE DIAL facility from four thermal infrared positive transparencies: Schenectady; Scotia; Cape Henlopen; and Stockbridge. In general, radiometric resolution was inadequate for vegetation discrimination. (Possibly the imagery was not acquired at the optimum time of day.) Spatial resolution was inadequate to marginal for the same purposes.

Figure 6 contains four of the seven digital images. At upper left is a subscene from the Cape Henlopen transparency. The other three subscenes were digitized from the Schenectady transparency. At upper right is a subscene derived from a 6 cm x 6 cm area on the transparency. The lower two images were digitized at higher spatial resolution from 2 cm x 2 cm areas. While spatial resolution here is adequate, vegetation classes are not clearly distinguishable because of poor radiometric data.

The Cape Henlopen subscene appeared to have the most appropriate scene content - woodland, grassland, bare fields, roads and residential areas.



Figure 3. Radar Image: Digitized (Upper)
and Original Film Recording (Lower)



Figure 4. Grassland Theme from Radar Image



Figure 5. Forest Theme from Radar Image.

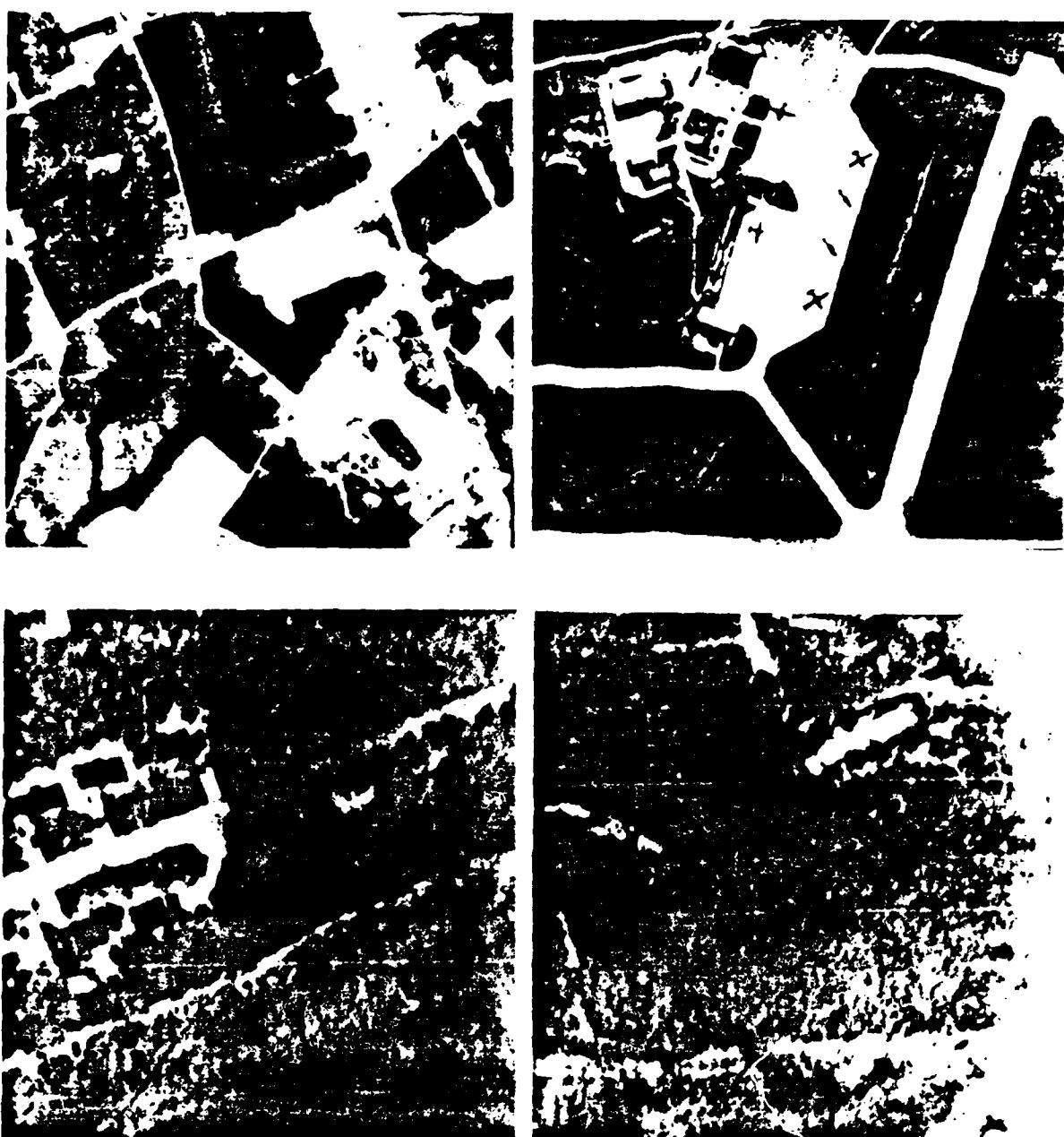


Figure 6. Digitized Thermal Infrared Images

Consequently a preliminary vegetation classification was attempted. The classification procedure normally uses the original digital image plus a texture version of that image. However, the spatial resolution in the digital image is not adequate for texture processing; only slicing of the gray-levels is possible. Results of attempts to discriminate woodland and grassland on the basis of thermal intensity only are shown in Figures 7 and 8. Comparing these results with visually observable scene features in the aerial photography for the same area, numerous classification errors of omission and commission are found. Therefore, the judgement is reached that radiometric and spatial resolution in this imagery are inadequate for acceptable vegetation mapping.

Preliminary vegetation discrimination using the digitized Stockbridge subscene indicated marginal utility for this image. Wooded regions could be separated from non-wooded regions, but not as well as with the panchromatic photography. Image spatial resolution was adequate, but contrast was low.

Thermal imagery has the potential to be a valuable supplement to imagery from other sensors. This was not assessed fully in the present study, and it should be examined in a future effort.

E. Panchromatic Photography

Thirteen panchromatic photographic transparencies were considered for use in this study: Scotia(2); Stockbridge(2); Schenectady(2); Cape Henlopen (2); and Fort Belvoir/Woodbridge(5). The transparencies have scales of 1:10,000 or 1:20,000, except for one Cape Henlopen image where the scale is 1:40,000. With the exception of the 1:40,000 scale image, there appears to be adequate contrast and spatial resolution in all transparencies for purposes of vegetation classification and forest element extraction.

A 512 x 512 pixel subscene from one of the Stockbridge transparencies was digitized in the GE DIAL facility and subjected to a preliminary vegetation classification. Acceptable results were achieved through the joint use of the digital image and a derived texture image (in which several



Figure 7. Woodland Theme from Thermal Infrared Image

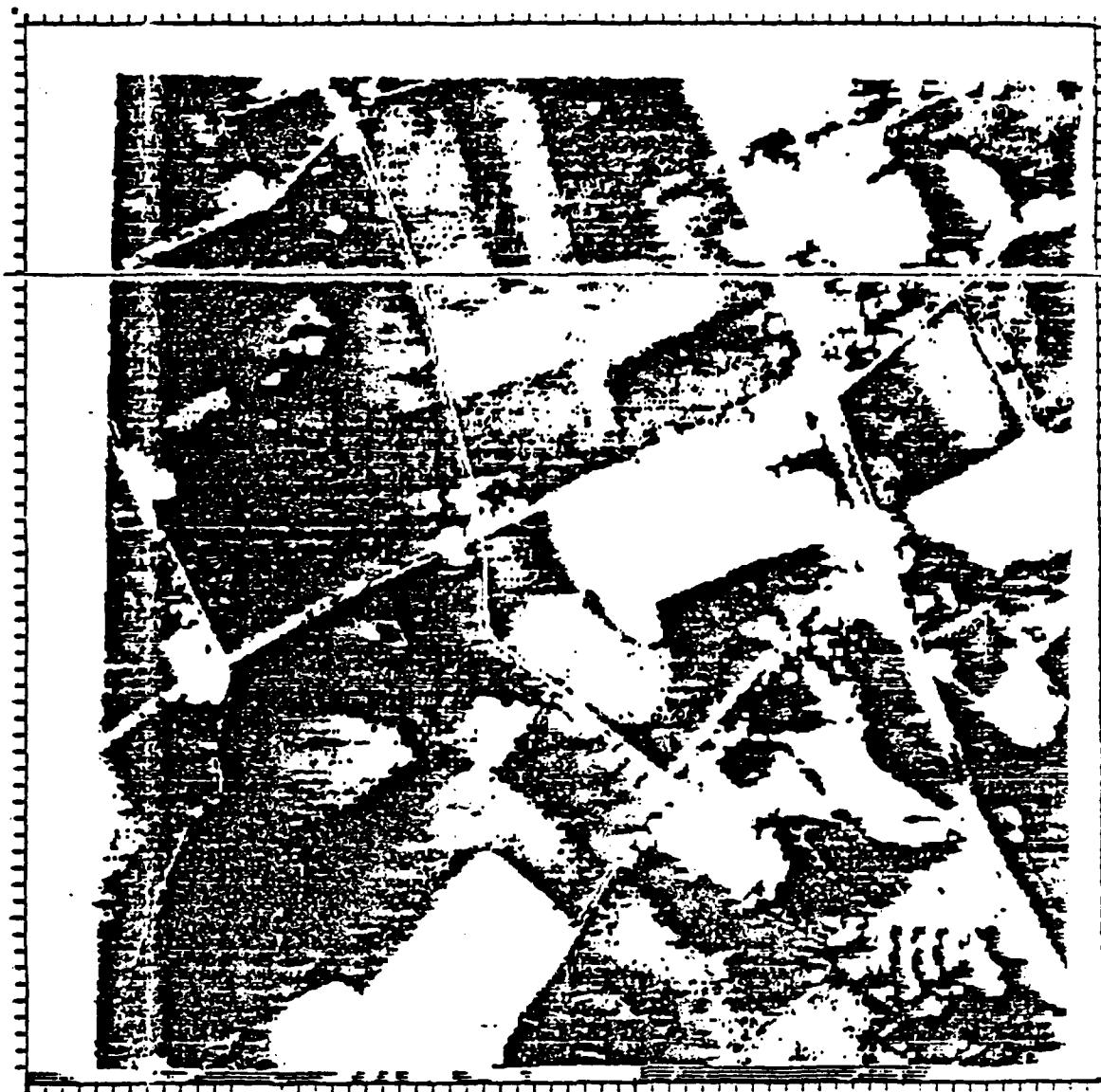


Figure 8. Grassland Theme from Thermal Infrared Image.

degrees of texture could be distinguished). The scene content, however, was not totally appropriate for purposes of this study (insufficient landcover diversity), and many of the other images were assessed similarly.

Three of the Fort Belvoir/Woodbridge transparencies appeared to have suitable spatial resolution, contrast and scene content, and 5 in. x 5 in. subscenes in each were identified for digitizing. In order to achieve a moderately high resolution digital image with a suitably large field-of-view, the three 5 in. x 5 in. subscenes were digitized via a scanning microdensitometer at USAETL. The resulting images, shown in Figures 9, 10 and 11, each contain about 1610 x 1610 pixels, with a pixel size approximately 2.7 ft. x 2.7 ft., and a subscene size of 4250 feet square. Production of digital images having these characteristics is beyond the capability available in the GE DIAL facility.

Two of the three Fort Belvoir/Woodbridge digital images are a stereo pair. Further, the digitized resolution (2.7 feet) is suitable for tree crown extraction (essential for forest-related terrain element extraction), and can support vegetation classification by digital manipulations which produce a more gross resolution. These three digital images are assessed as having high utility for purposes of this study.

F. Pennsylvania Multispectral Scanner Data

Digital multispectral scanner data are not included among the imagery types specified for consideration in this study. However, because of the difficulty in acquiring sufficient suitable imagery of the types that were specified, the use of multispectral scanner data to simulate other data becomes a desirable alternative. Further, since such scanner data contain both thermal infrared and visible region channels, the possibility exists for simulating the joint use of panchromatic photography and thermal imagery. Suitable scanner data, particularly from flights over an area of Pennsylvania containing an applicable mix of scene features, was available in the General Electric Company and was, therefore, given consideration for use in the study.

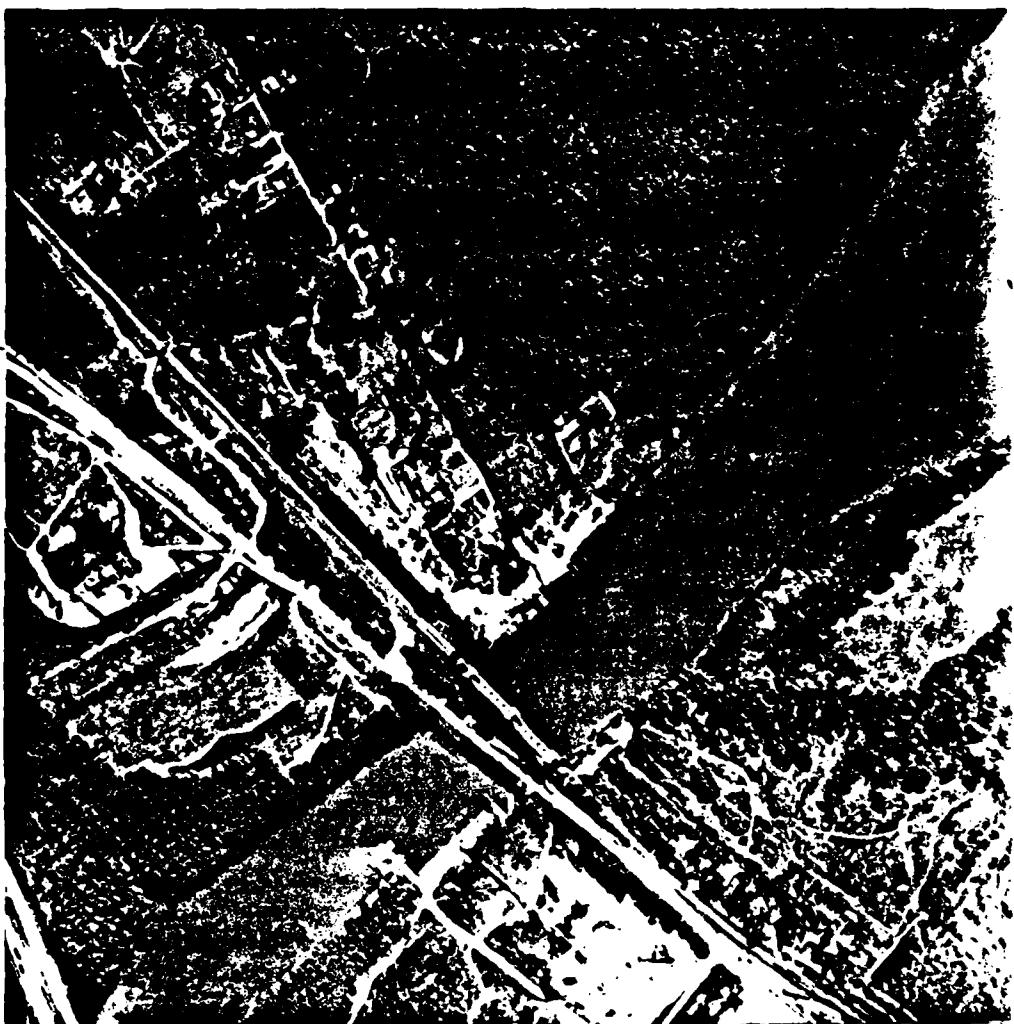


Figure 9. Digital Recording of Fort Belvoir/Woodbridge Panchromatic Photograph (A)



Figure 10. Digital Recording of Fort Belvoir/Woodbridge Panchromatic Photograph (B)



Figure 11. Digital Recording of Fort Belvoir/Woodbridge Panchromatic Photograph (C)

The Pennsylvania scanner data source is the 11-channel Daedalus Scanner (DS-1260 system) which was flown over Clarion County, Pennsylvania on May 17, 1979 by the EPA. Data were collected for the same scene at three altitudes: 20,000 feet, 10,000 feet and 5,000 feet. Spatial resolution for the data at these altitudes was approximately 44 feet x 36 feet, 22 feet x 18 feet and 11 feet x 8 feet, respectively. Figure 12 shows the coverage in the scene for the three data altitude sets. Actually, the scan line lengths (coverage strip width) are larger than shown in the figure, but scan lines 512 pixels wide were extracted from the source data for use in this study. It can be seen that there are regions in the scene in which there is multi-altitude data coverage.

The following are some of the scanner characteristics of interest in this study:

• Swath width	- 77°
• IFOV	- 2.5 mrad.
• Roll compensation	- Signal ($\pm 10^{\circ}$)
• In-flight calibration	- Black bodies, Q-I lamp
• Recording	- 14-track digital mag. tape
• Spectral bands	- Near-contiguous coverage from 0.38 to $1.10 \mu\text{m}$ in 10 channels, plus an $8-14 \mu\text{m}$ channel

Of the eleven scanner channels, two are of particular interest for this study: Green (0.50 - $0.55 \mu\text{m}$); and Thermal IR ($8-14 \mu\text{m}$). Figure 13, 14 and 15 show digital recordings of the green and thermal IR scanner data at each of the three altitudes. These image recordings are presented at a scale of 1:50,000.

For the purposes of this study, particularly for vegetation/land cover boundary extraction, the Pennsylvania multispectral scanner data sets are assessed as having high utility.

G. Florida Multispectral Scanner Data

The Bendix 11-channel Modular Multispectral Scanner was flown over central Florida, west of Orlando, in November 1977. Data acquisition, for the U.S. Department of Transportation, was at an altitude of 2000 feet, resulting

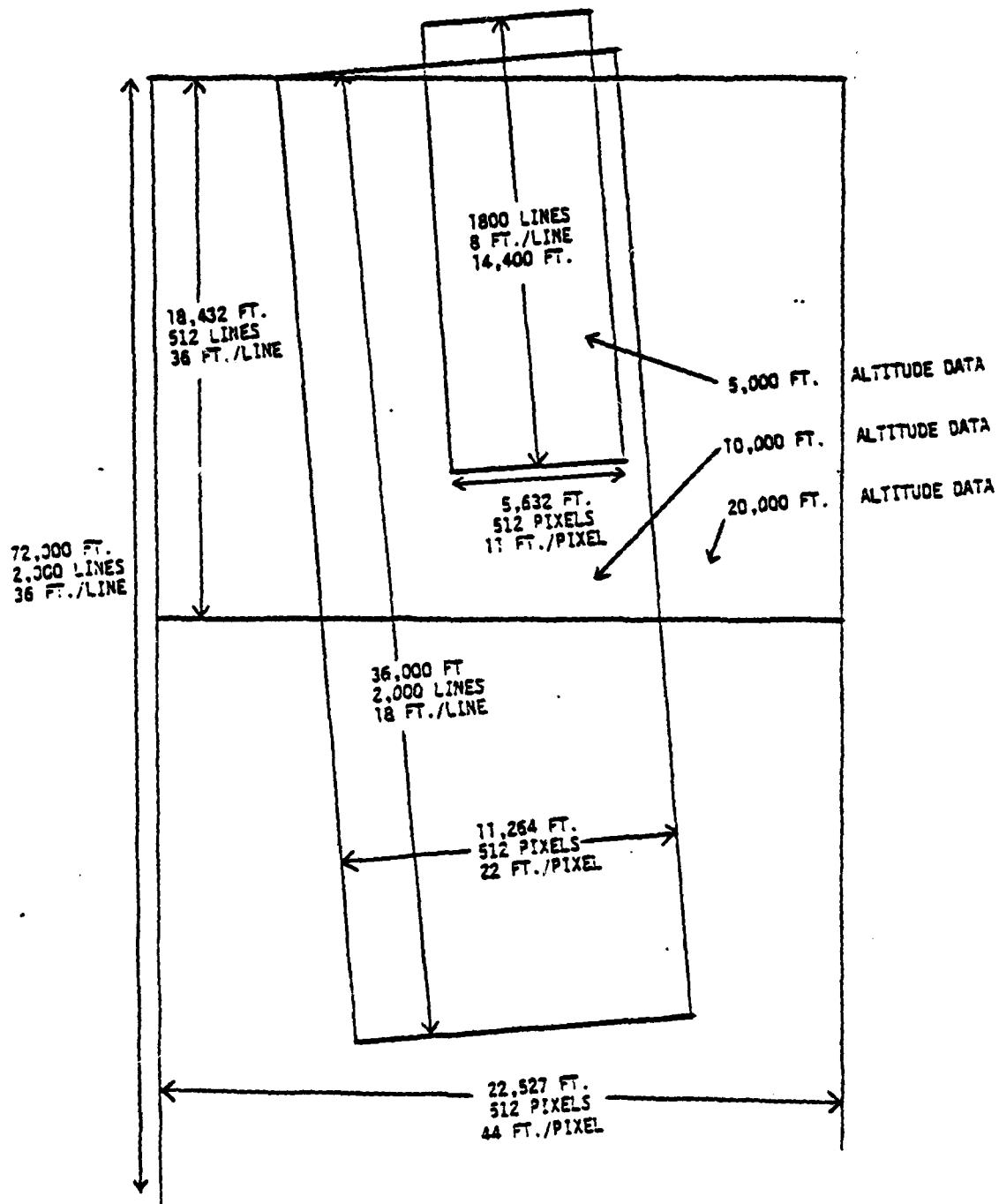


Figure 12. Pennsylvania Scene Multispectral Scanner Coverage.

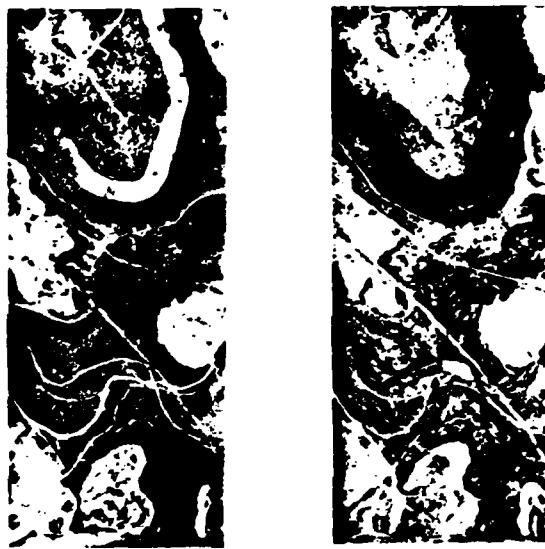


Figure 13. Pennsylvania 5000-Foot Altitude Scanner Image:
Green (Left) and Thermal (Right)

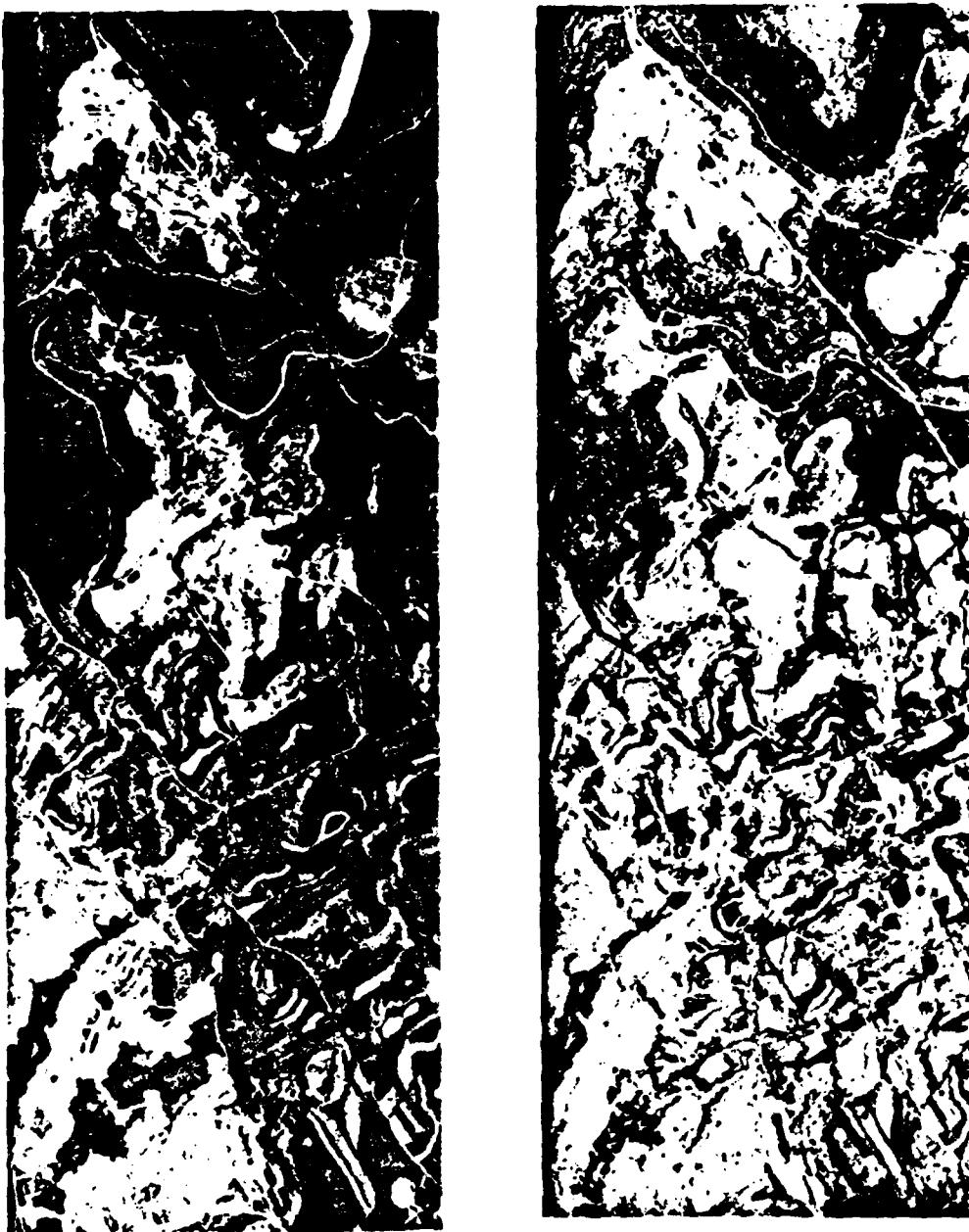


Figure 14. Pennsylvania 10,000-Foot Altitude Scanner Image:
Green (Left) and Thermal (Right)

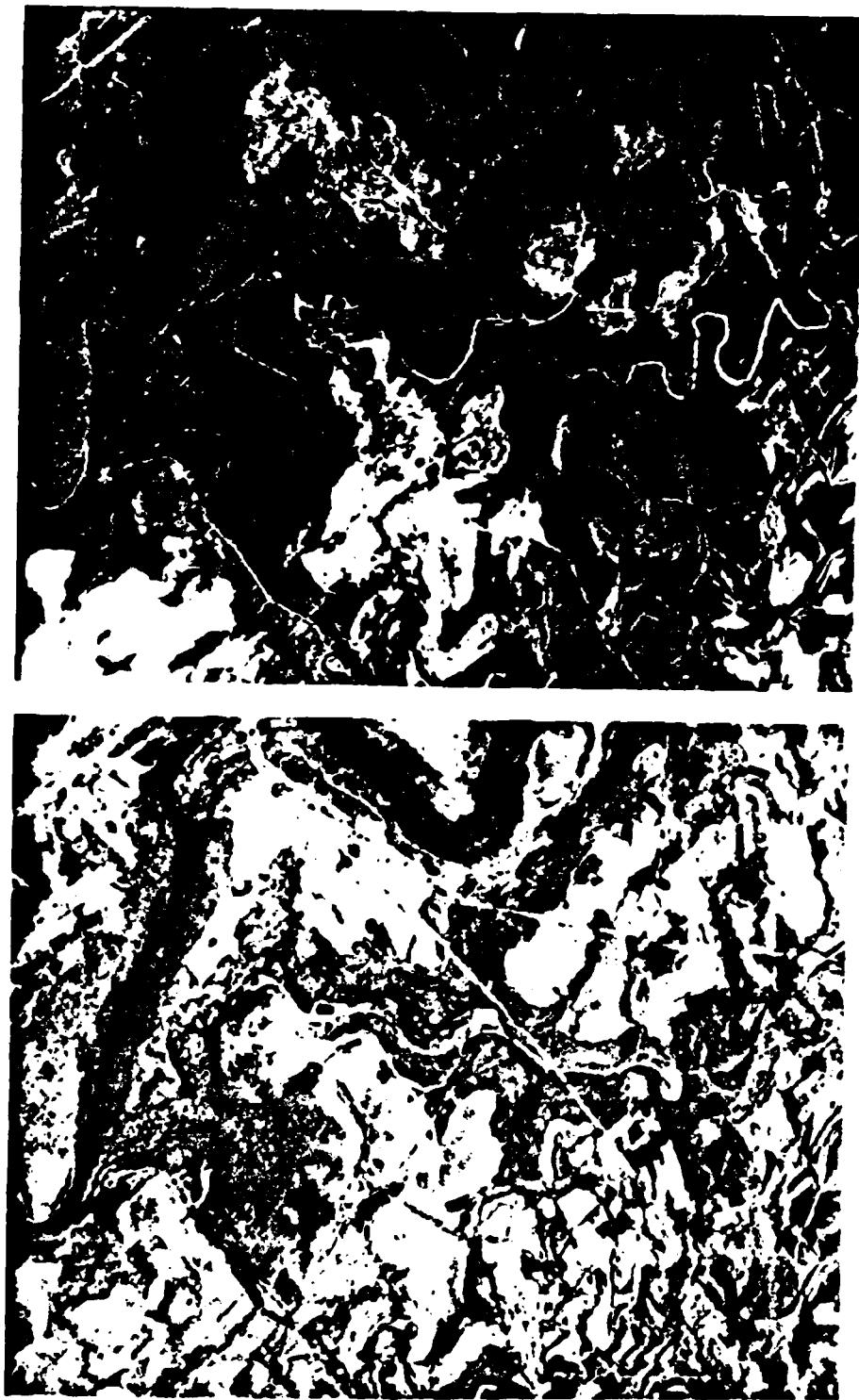


Figure 15. Pennsylvania 20,000-Foot Altitude Scanner Image:
Green (Top) and Thermal (Bottom)

in data resolution of approximately five feet. A few 512 x 512 pixel subscenes from this image data were available in the General Electric Company. One such digital subscene is considered to be an appropriate candidate image for use in this study. The subscene features include woodland, citrus plantation, grassland, bare areas and water.

As in the case of the Pennsylvania multispectral scanner data, the green (0.49-0.54 μ M) and thermal infrared (8-12 μ M) channels are of particular interest. Figure 16 presents the subscene digital images for these two channels.

The following are some of the pertinent scanner characteristics:

- Swath width - 100°
- IFOV - 2.5 mrad.
- Roll compensation - Signal ($\pm 10^0$)
- In-flight calibration - Black bodies, Q-I lamp
- Recording - 14-track digital mag. tape
- Spectral bands - 0.38-1.05 μ M nearly contiguous coverage in 10 channels, plus one 8-12 μ M channel

H. Imagery Selected for Use in the Study

From the total imagery considered, the following were selected for use during the remainder of the study (i.e., for development of vegetation data extraction techniques):

- Fort Belvoir/Woodbridge Panchromatic Photography
 - 3 digital subscenes (two are a stereo pair), each covering an area 4250 feet square
- Pennsylvania Multispectral Scanner Data
 - Digital data sets for flights at three altitudes, each set covering several square miles and containing image data in the Green and Thermal Infrared bands
- Florida Multispectral Scanner Data
 - One 512 x 512 pixel subscene, covering an area 2500 feet square, and containing image data in the Green and Thermal Infrared bands.

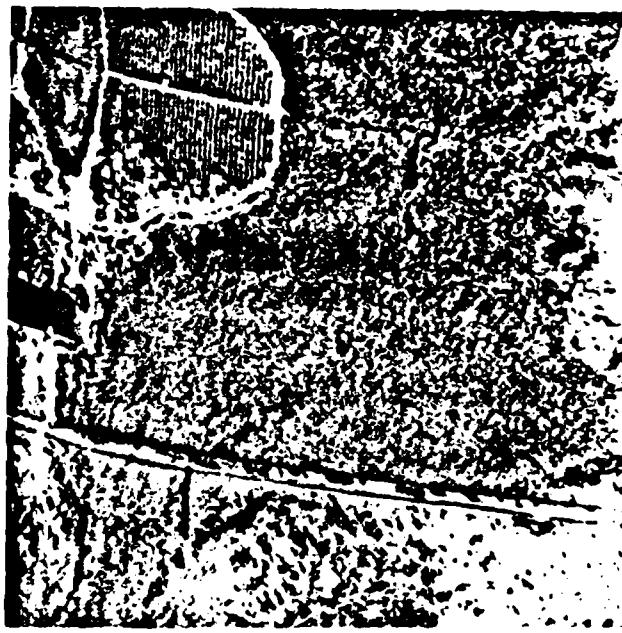
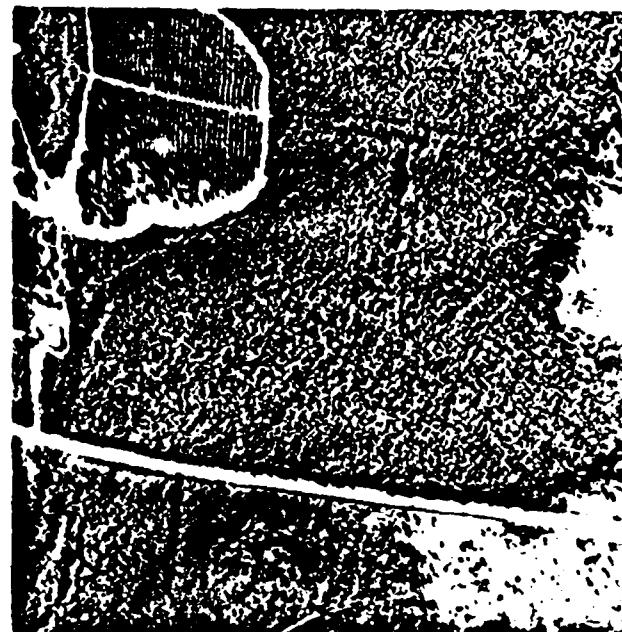


Figure 16. Florida Scanner Image:
Green (Top) and Thermal (Bottom)

III. EXTRACTION OF FOREST-ASSOCIATED TERRAIN ELEMENTS

A. Introduction

Extraction of many of the forest-associated vegetation elements can be approached in either of two ways using an interactive analysis system. The first is to use the system as a means for making the measurements and extracting the data step-by-step directly in accordance with the manual element extraction procedures (as outlined in the Procedural Guides). The second is to use the system interactively to extract certain key data, and then store the data in a form which can be used by the computer to complete the element generation automatically. Some of the vegetation elements (e.g. stem diameter histograms) are very tedious to extract manually. A significant contribution could be made by automating the procedure.

A total of six vegetation elements (elements numbered 3-8 in the procedural guide for vegetation element extraction) are ultimately derived from only two basic forest properties, both of which are normally extracted by the photo analysis for each forested area. These properties are individual tree crown areas (both areal extent and fraction of closure), and individual tree locations.

Some advantage can be realized when mapping these properties via interactive means. With manual interpretation the analyst must limit his effort to a sample of each investigated area, since examining the entire scene in detail would be prohibitively time-consuming. Extraction of this information via unassisted computer techniques over sizeable portions of an image is likewise unfeasible, because of the wide variation in scene content and in the radiometric differences across and between scenes.

Effort has been made to develop techniques for mapping tree cross-sections and canopy extent on a scene-wide basis by using highly interactive computerized image analysis. The computer is used not primarily as a decision making device, but as a means of preprocessing, classifying, and post-processing data based on decisions which are made by the image analyst. An interactive system is used to display black-and-white image data, along

with additional images derived from the raw data which present spatial information, such as texture, in a pictorial format. Critical decisions are made and optimized through the viewing of histograms describing these data and through real-time interactions with the displays. The analyst adjusts level-slicing thresholds in both the original and derived images while viewing the slice results as a binary map or "theme" superimposed on the original image.

With the basic forest information accurately determined, and stored as image format binary maps, extracting the five forest-related vegetation elements becomes a computer processing task with little additional interaction required. The actual elements can be represented in a data base by gray-level maps, where the gray-level of each pixel is a value or local average of values for the element at the corresponding point in the original image.

Factor overlays, which are the ultimate product of this effort, can then be produced quickly by applying existing image processing techniques to each gray-level map. Line format overlays can be made by contouring the maps or by level slicing and outlining the slices. Numeric information can be retrieved via calibration of the gray-levels, or by generating histograms of the levels.

Table 2 lists six vegetation elements which could be easily generated by computer, given the proper input. As shown by the table, all of these elements can be derived from only three thematic maps: (1) A Forest theme which maps forested areas into a large, contiguous block; (2) a Canopy theme which accurately maps canopy foliage, leaving out inter-tree gaps and shadows; and (3) a Crown theme consisting of individual pixels which locate each tree crown in the image. It is critical that each of these themes be as accurate as possible.

B. Forest Theme

One of the first steps in the analysis of forest related vegetation elements is the development of a "forest area theme." The theme might be defined as a smooth contiguous mapping of all the forested areas. It

Table 2. Automated Vegetation Element Extraction

#	ELEMENT	INPUT			PROCEDURE	NUMBER- IC	GREY- LEVEL	SPOT VIDEO	GRAPH- IC
		FOREST THEME	CANOPY THEME	OTHER ELEM.					
3	% CANOPY CLOSURE				MOVING AVERAGE OF CANOPY THEME				
4	STEMS / HECTARE				MOVING AVERAGE OF CROWN COUNT THEME				
5	CROWN DIAMETER				1 ha. MOVING WINDOW DI- VISION: $\text{CROWN DIAM. } = D = k \cdot \sqrt{\frac{\text{CANOPY}}{\text{CROWN}}}$	5	SELECT FOREST MODEL FOR a AND b		
6	STEM DIAMETER				STEM DIA. = $S = b \sqrt{\frac{D}{a}}$				
7	STEMS / DIA / ha					6	GET HISTOGRAM FROM 6 AND CALIBRATE		
8	STEM SPACING						4	CALCULATE FROM STEMS/ HECTARE	

should be similar in nature to what an analyst or forester would have mapped manually. It should be characterized by a boundary of realistic geometric complexity (smoothness) so that when presented as a line map, it is immediately interpretable. It should not depict small isolated clumps of trees or small forest clearings, both of which would be omitted by a photo analyst.

An outline of the forest theme serves directly as a vegetation element (vegetation boundary). The theme itself will be used frequently in subsequent element extraction to restrict maps and numeric information concerning forest-related elements to within forested areas.

For the test images investigated, development of forest themes was a relatively easy task. Each image proved to be a unique case with its own set of problems, but techniques such as smoothing and texture extraction were applied as necessary and proved successful. Section V contains a detailed description of the technique and procedures used. A summary of the general procedure is presented in Figure 17.

It is notable that forest theme extraction was particularly easy using thermal infrared data for the Pennsylvania test site. While the resolution of this image was on the order of a few feet, resolving small isolated trees, the forest canopy was imaged as a large, nearly featureless area of uniform temperature. A suitable theme was produced directly by density slicing.

In general, processing techniques including smoothing and texture extraction were necessary to produce a suitable theme. The recurring problem was that imagery with sufficient resolution to allow detailed forest analysis contained too much fine structure for direct forest mapping. The most widely successful approach was to apply a spatial low-pass filter to the data, degrading resolution to the point where individual trees of the forest canopy were no longer resolvable. The smoothed image could then be sliced to produce forest maps with suitably limited geometric complexity. For the most difficult images, which contained water, fields or

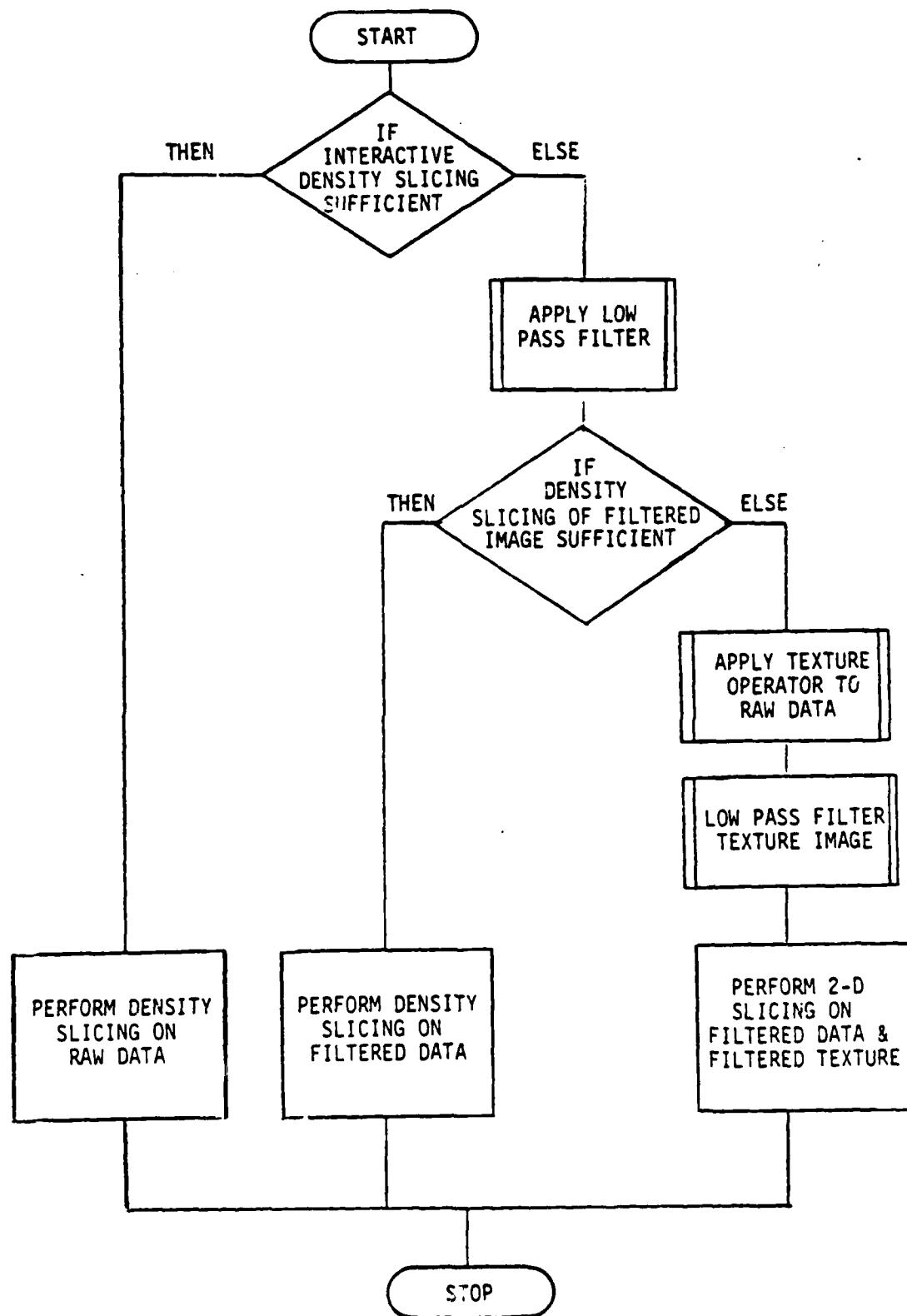


Figure 17. Procedure for Forest Theme Extraction.

pastures each represented with a mean density similar to that of the forest, a textural operator was applied to generate a secondary image. Two-dimensional level slicing, applied to the smoothed data and to a smoothed form of the textural image, was sufficient to map forests in all the images investigated.

Figure 18 is an example of a forest theme. It was generated from the Fort Belvoir/Woodbridge panchromatic photography image data.

C. Canopy Theme

Classification of the forest canopy (the actual foliated area of the forest) proved to be a surprisingly difficult task, with most of the difficulty being encountered in the shadowed regions. As with manual photo analysis of the canopy, a high degree of analyst judgment must be used to handle these areas. The shadows falling on other crowns must be included in the canopy map. This requires that more than a single density slice or other "signature" be used in order to completely map the canopy area.

While classifying the fully illuminated portions of the canopy is straightforward, working in the shadow areas leads to several problems. Shadows are generally reproduced in photographic images in the extreme lower end of the characteristic curve, resulting in a very restricted density range. As a consequence, small variations in slice thresholds produce considerable differences in the area mapped, and allow only a very low margin for error. Differences in image radiometry associated with lens fall-off and with scattering angle differences, which might be incidental for some mapping tasks, assume levels of major importance.

The Fort Belvoir/Woodbridge test image, which can be considered typical, was acquired with a 6-inch lens and included diversified forest stands. Density slicing was insufficient to map the canopy. An approach that finally proved successful involved classifying the canopy area in two steps. The first uses the forest theme, previously generated by slicing a low-passed version of the image, to make a mask containing all canopy areas. The second step uses the full resolution available to remove the finely structured gap and hole areas that were not actual canopy area.

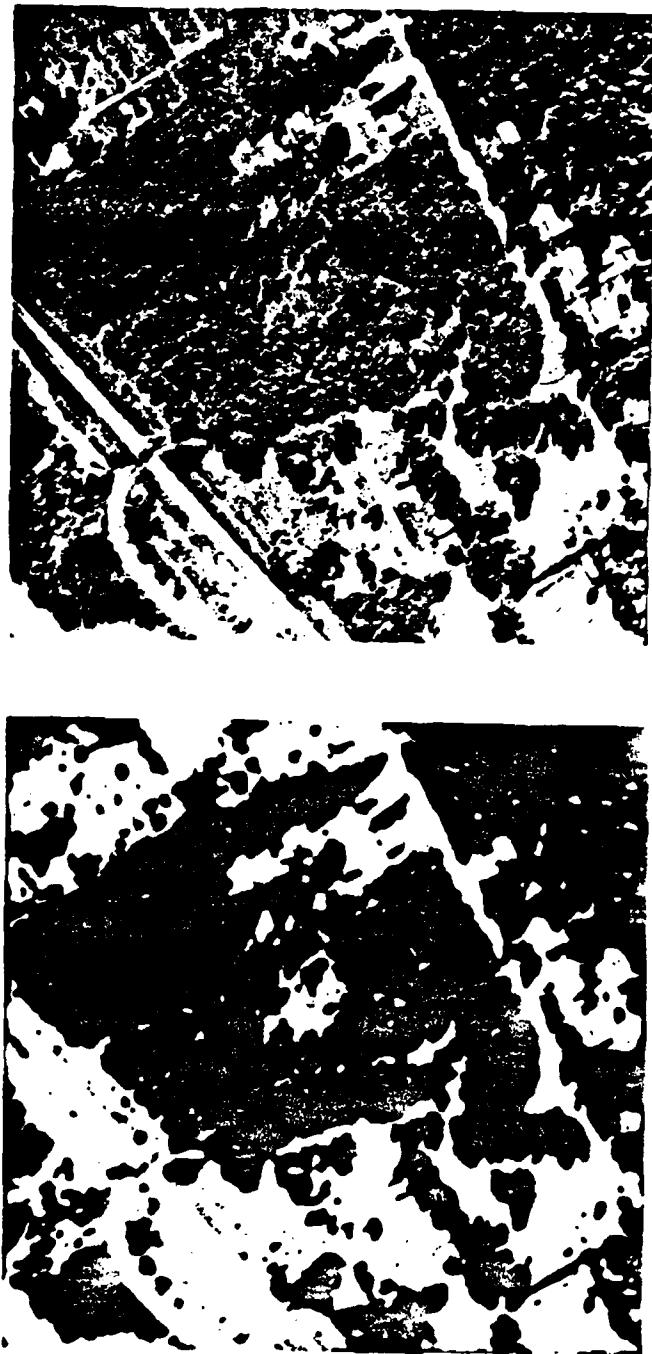


Figure 18. Forest Theme From Fort Belvoir/Woodbridge Subscene
(Bottom, Black), and Original Digital Image (Top)

Deep shadows were best extracted by performing interactive two-dimensional density slicing on a full-resolution version of the original image and (jointly) the derived texture image. The texture output, being extracted from local image areas only, is nearly immune to slowly varying radiometric differences. This enables separation of the very deep shadows from the texture containing shadows associated with partially illuminated canopy areas. The resulting canopy map produced for the Fort Belvoir/Woodbridge subscene is shown in Figure 19.

D. Crown Theme

1. General Approach

One of the more important techniques developed during this study is the capability to quickly identify and locate individual tree crowns, whether they are isolated or part of a fully-closed forest canopy, and to store that information in a manner suitable for subsequent computer processing. The technique is a very basic forest analysis tool which can be used to extract information key to several vegetation elements. Crown diameter, stem diameter, stems per hectare and stem spacing are all elements where extraction requires information on individual tree locations and where extractions could be highly facilitated or even automated with a good crown-locating algorithm. Since manual crown counting is a tedious and sometimes difficult task, computer assistance offers the possibility for significantly reducing the time required for crown counting, and the possibility for improving the accuracy of a sometimes subjective task.

The approach taken involves finding a means for classifying a contiguous portion of each crown with no omission error (no trees left without some portion included in the classification). The classified image is then smoothed as necessary to eliminate complex shapes and remove holes so as to create a map of simply shaped areas (blobs), one for each tree. Finally, each of these mapped areas (blobs) is reduced to a single picture element by applying an area-shrinking or blob-counting algorithm to the map. The picture elements remaining after the shrinking operation provide an easy method of finding both the number of crowns in any area, and their spatial distribution.

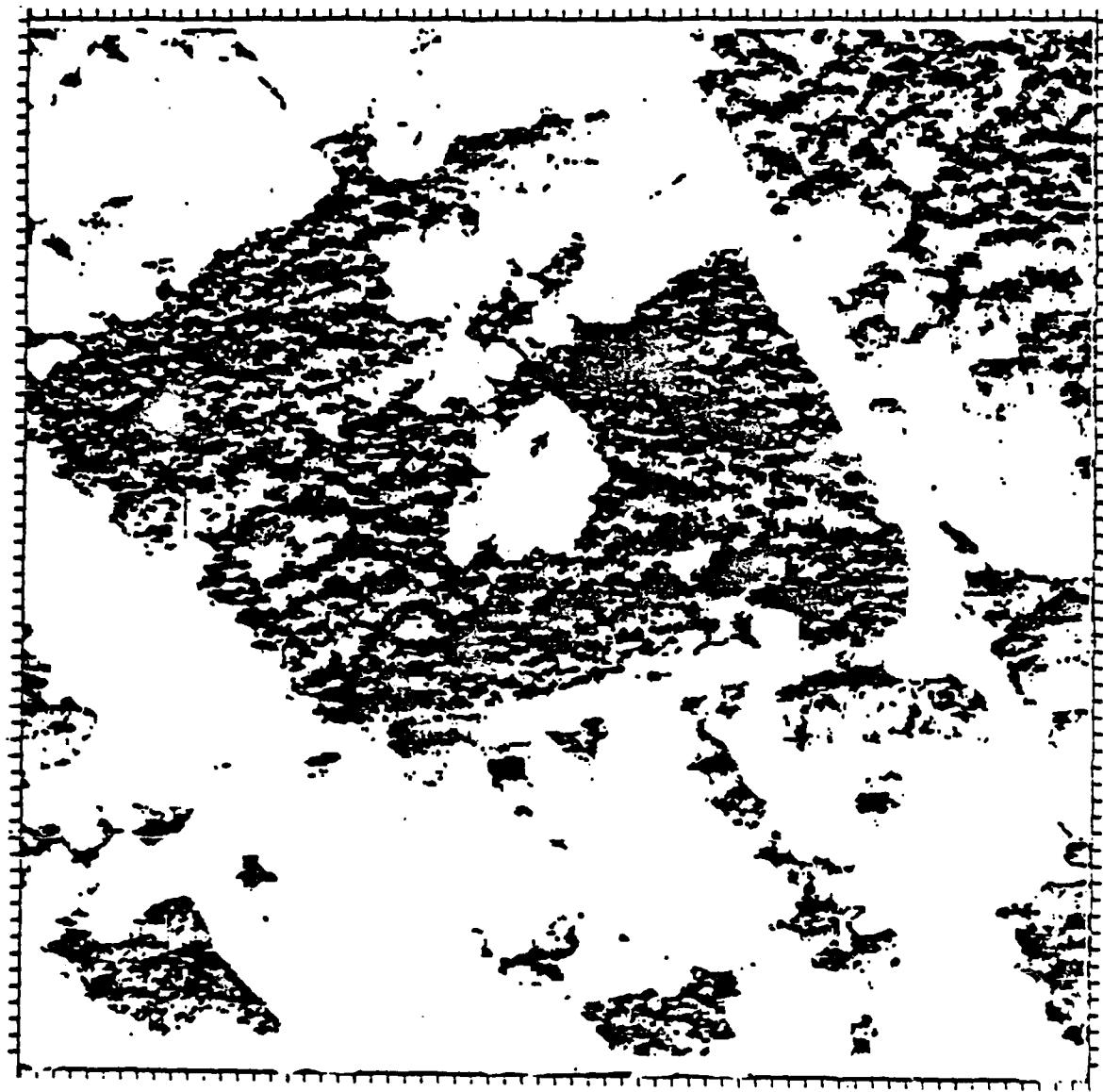


Figure 19. Canopy Theme

Direct classification of crowns by simple density slicing is sometimes possible and can be very effective when mapping well separated crowns. Groves and plantations can usually be processed in this manner. These are, however, highly idealized situations and not indicative of the level of image complexity that a generally applicable crown-locating method must handle. Separation of individual crowns in a densely forested area is usually not feasible by simple density slicing. The most common problem is that while a single slice may be satisfactory for a small image area, differences in forest configurations and in image radiometry make a single slice inappropriate for larger areas.

2. Crown Templates

For the general case, crowns are better located by making use of their somewhat unique and simple spatial properties. This can be done by applying a template operator, which senses round objects in the image. A secondary gray-level crown-locating image is made by convolving the original data with the template. Over individual small objects the template operator computes a local weighted average which varies whenever a crown-shaped or circular object is located. The amplitude of the variation is dependent upon how closely the object fits the template, and upon the difference in brightness between the object and its immediately surrounding area. Templates are usually numerically scaled so that the nominal output value (value when no fitting objects are encountered) is zero. For display purposes, this output is offset by some constant gray-level so that both positive and negative values can be presented. The output image then has a uniform overall intensity, which corresponds to a template output value of zero, and contains lighter or darker areas at every location where the template fits an object. Density slicing on this secondary image can be used to produce a map which locates the brightest areas, and this is an effective means for mapping objects with similar spatial characteristics (e.g., tree crowns).

3. Template Selection and Testing

Trees in a forest are found, on close inspection, to be a varied lot with respect to individual sizes, shapes and degrees of crown closure. For

any tree, the average image brightness is dependent on species and tree condition. The shape of its crown is determined by the proximity of neighboring trees. To be effective, a template must make use of whatever characteristics these varied crowns have in common. Usually, these characteristics are only roughly circular in shape, with the center brighter than the edges. The template should not be designed to fit some "typical" tree exactly, but should be a rather loosely fitting mask which responds to the widest possible range of crowns. It must also respond to crowns set against a wide range of backgrounds.

The templates shown in Figure 20 were among those tested. They are all empirically derived, and elements are scaled in accordance with a few constraints: (1) the sum of all elements must be zero, (2) the central elements are heavily weighted to sense the average gray-level of a small object, (3) the template must cover an area larger than an individual crown in order to obtain a local average image brightness.

To efficiently evaluate crown templates without being confronted by scale problems, an image (Figure 21) containing a forest canopy at multiple scales was created. The image (upper left or lower right in the figure) is a video scanner subscene digitization (in the GE DIAL facility) of one of the Fort Belvoir/Woodbridge area panchromatic aerial photographic images. The five sections each represent the same ground area. The ratio of the scales for any two adjacent sections is roughly the square root of two. Any of the templates applied should fit one of the scales reasonably well. Other images in the figure show a typical secondary image (upper right) resulting from a crown template, and a binary crown map (lower left) derived by slicing the brightest levels from the secondary image.

Performance of the templates tested ranged from satisfactory to very poor, so initial screening was done on a purely experimental basis. Each template was applied to the test image, and the resulting secondary "crown" image was qualitatively evaluated based on how well level slicing produced blobs which corresponded to individual trees. The results showed that most of the crown templates perform satisfactorily on small scattered

-1	-1	-1		-1	0	-1	0	-1
-1	8	-1		0	0	0	0	0
-1	-1	-1		-1	0	8	0	-1
				0	0	0	0	0
				-1	0	-1	0	-1

-1	-1	-1		-1	-1			
-1	0	1	0	-1	-1	2	2	-1
-1	1	8	1	-1	-1	2	2	-1
-1	0	1	0	-1	-1	-1	-1	
-1	-1	-1						

-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	0	0	0	0	0	0	0	0	-1
-1	0	0	4	0	0	-1	0	2	4
-1	0	4	4	4	0	-1	0	4	5
-1	0	0	4	0	0	-1	0	-2	3
-1	0	0	0	0	0	-1	0	0	0
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Figure 20. Some Crown Templates Tested

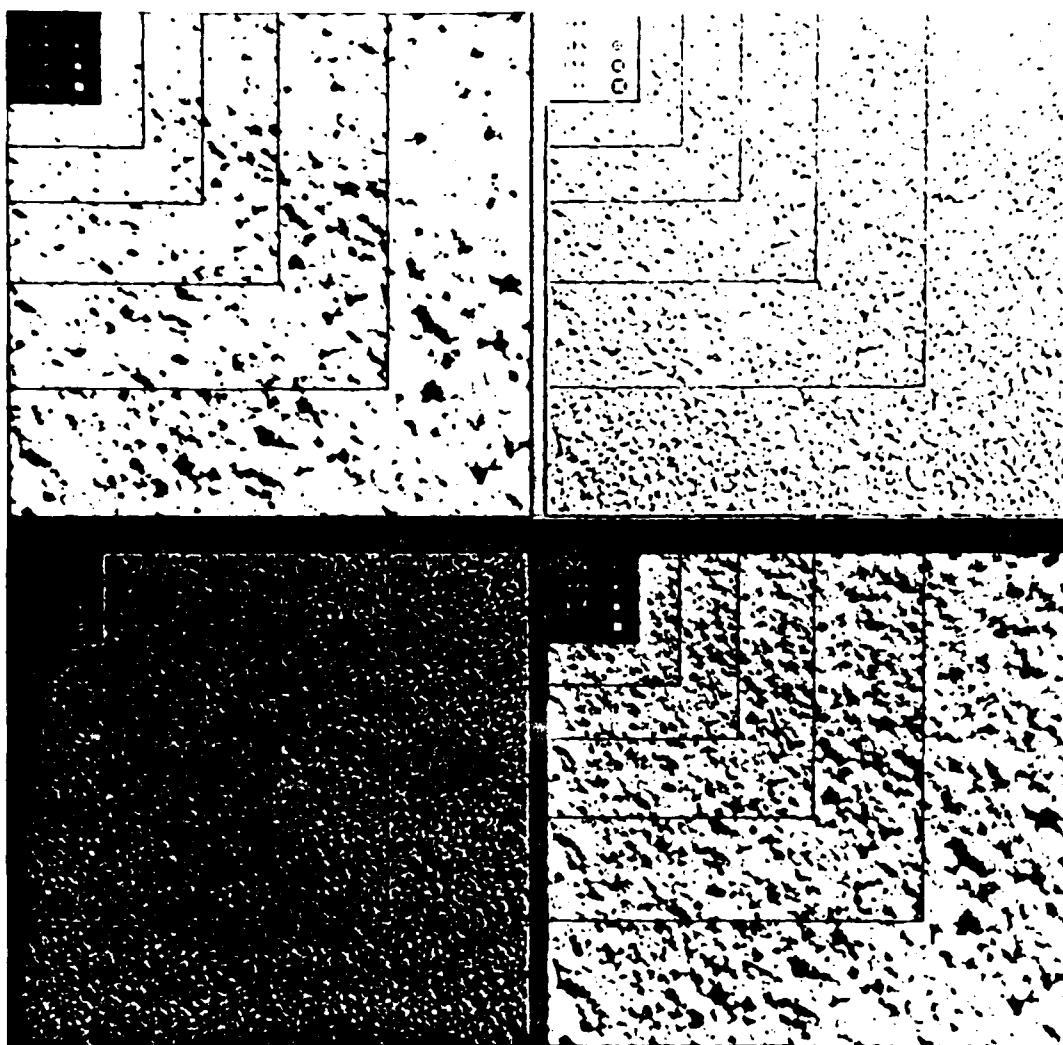


Figure 21. Multi-Scale Image for Crown Template Testing

trees and locate them with near certainty. Densely forested areas, however, proved to be a very stringent test, and it is important that they be included in the selection process.

Small templates, those covering a 3×3 pixel area, created a very "noisy" output and were quickly realized as being too sensitive to small area bright spots. Further consideration of these templates was dropped. The larger templates tested (7×7 pixels) generally produce a smoother output, but some were too scale dependent and would not handle a satisfactory crown size range.

Of the templates investigated, those of the form shown in Figure 22 appear most promising. The central template elements weigh the crown area itself, which should extend over several pixels, and the outer ring of elements compute a 20-pixel average of the surrounding area. The annular ring of zeros serves to make the template relatively insensitive to variations in crown size. This template output is also smooth and does not seem to require additional filtering to map contiguous blob like areas.

4. Threshold Sensitivity

To determine how well the crown locating and counting procedure performed, the template of Figure 22 was used with the image of Figure 21 (one scale only). Instead of density slicing by interactive means, the template output (see histogram in Figure 23) was thresholded, and contiguous areas (blobs) created by levels greater than the threshold were digitally counted. This was repeated for several threshold levels (or histogram rejection levels). A comparison of the number of crowns counted vs. histogram rejection level is shown in Figure 24.

Originally, it was felt that careful interaction by the analyst would be required to set a critical rejection level, but the graph in Figure 24 shows this may not always be necessary. When the rejection level was set below 55%, the blobs formed were of complex shapes and often left no gap between crowns. The blob counter which was used does not handle complex blobs well, and the resulting count was clearly too high. At the other

CROWN TEMPLATE

	-.125	-.125	-.125	-.125	-.125	
-.125	0.0	0.0	0.0	0.0	0.0	-.125
-.125	0.0	0.0	0.5	0.0	0.0	-.125
-.125	0.0	0.5	0.5	0.5	0.0	-.125
-.125	0.0	0.0	0.5	0.0	0.0	-.125
-.125	0.0	0.0	0.0	0.0	0.0	-.125
	-.125	-.125	-.125	-.125	-.125	

— — — →
TEMPLATE
MOVES
THROUGH
SCENE

Figure 22. Preferred Crown Template.

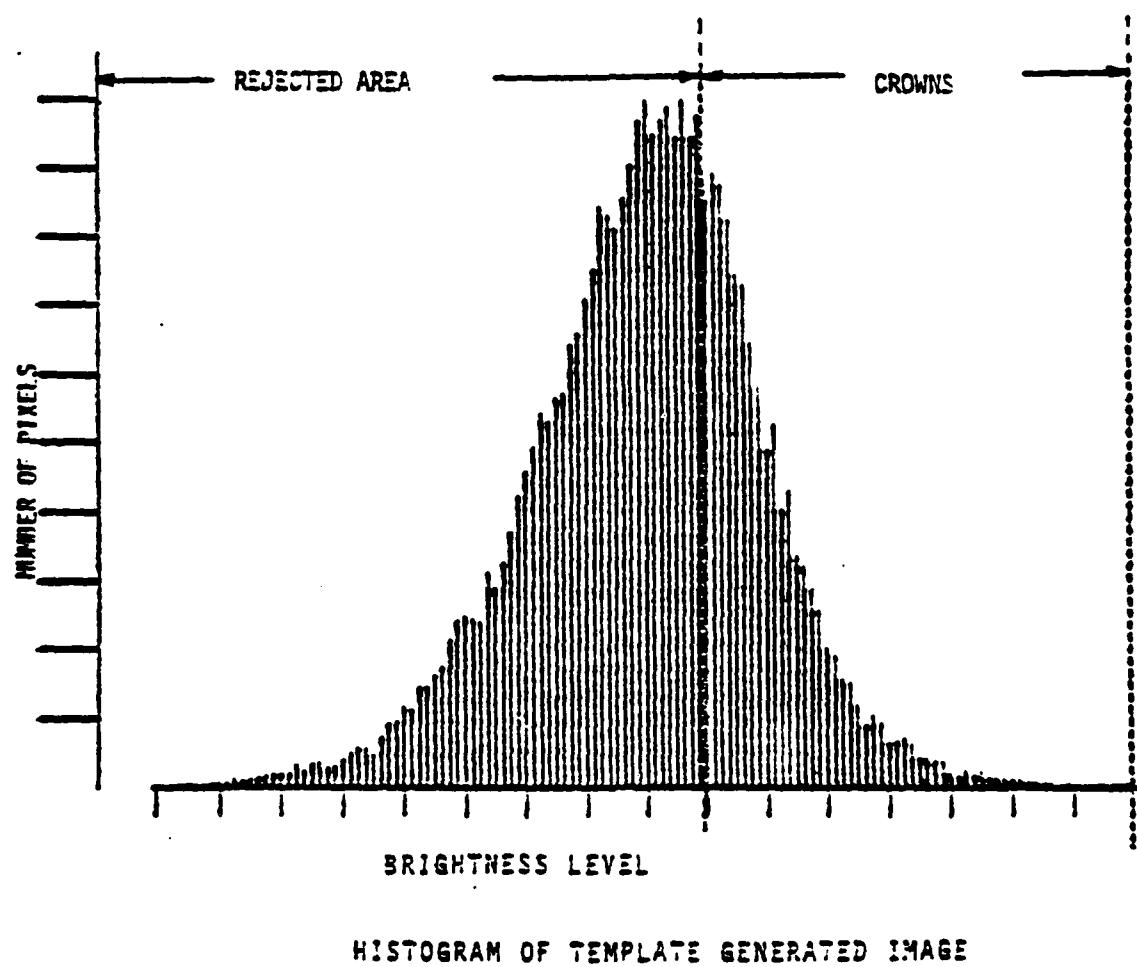


Figure 23. Histogram of Template Generated Image.

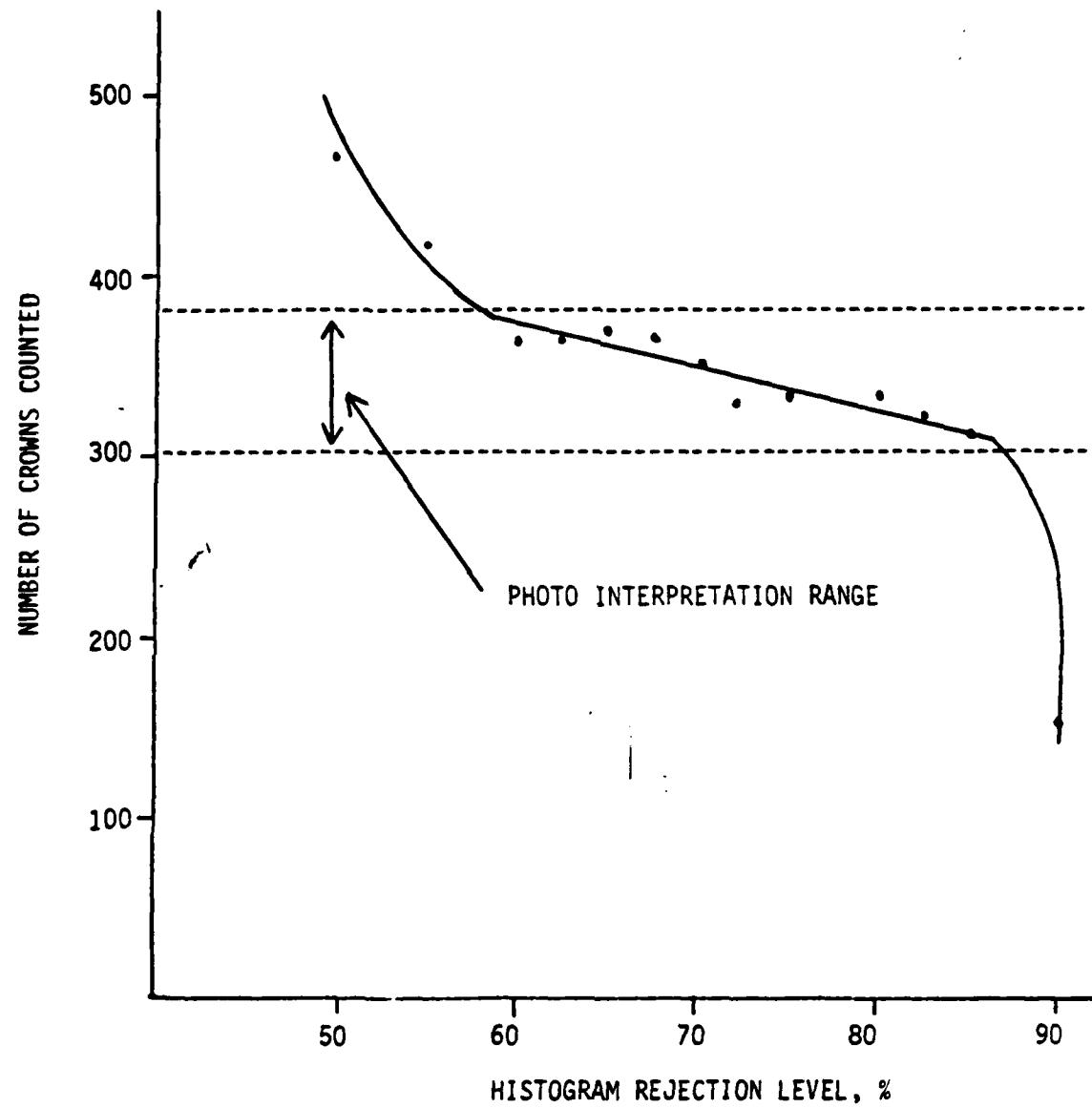


Figure 24. Crowns Counted vs. Histogram Rejection Level.

extreme, with greater than 85% rejection many crowns were not classified at all, resulting in an erroneously low count. Between these two thresholds the number of crowns counted was surprisingly insensitive to exact rejection level. In this region the number of crowns counted ranged only by approximately $\pm 10\%$ from the mean.

The crowns in the test area were then counted manually by four different people to determine what the number of crowns "should" have been. The analysts (not highly skilled photointerpreters) failed to show any improvement over the automated counting. Two of the four counted about 375 crowns in the test area, while the other two found only about 315. The lower number probably describes the primary canopy of large, uniformly sized crowns. The interpreters who estimated high took significantly longer to perform the counting, and they were evidently including many smaller crowns from the secondary canopy. Even with stereo imagery it is not always clear if the smaller crowns represent individual trees or large branches of single trees. It appears that the counting algorithm will be acceptable, proving to be as consistent as were the small sample of analysts, and performing the task in significantly less time. The analyst can still retain control and "fine tune" the algorithm by adjusting the histogram rejection level to suit the situation.

5. Scale Sensitivity

The crown template counting method was also tested for sensitivity to tree size variations using an image segment containing a fully closed canopy. The segment was extracted from the Fort Belvoir/Woodbridge area panchromatic photograph and was digitized at nine different spatial sampling rates using the GE DIAL video scanner. Scales were incremented by $\sqrt[4]{2}$. The image segment contained a fairly diverse section of forest, and is typical of the forest diversity that must be handled in a working situation. Within the segment, size variation for individual tree crowns spanned a 3X range, with 2X variations being commonplace.

In a manner similar to that for the threshold sensitivity test, the selected template was applied to the multi-scale test scene, and the template output was level-sliced at a nominal threshold which produced

contiguous blobs. Crowns (blobs) were then counted for the mapping at each image scale. Figure 25 shows the results of the counting. The number of crowns in each image segment is plotted against the segment scaling. The number of crowns was plotted on a logarithmic scale to make more apparent the region of the plotted curve where the template best fits the crowns.

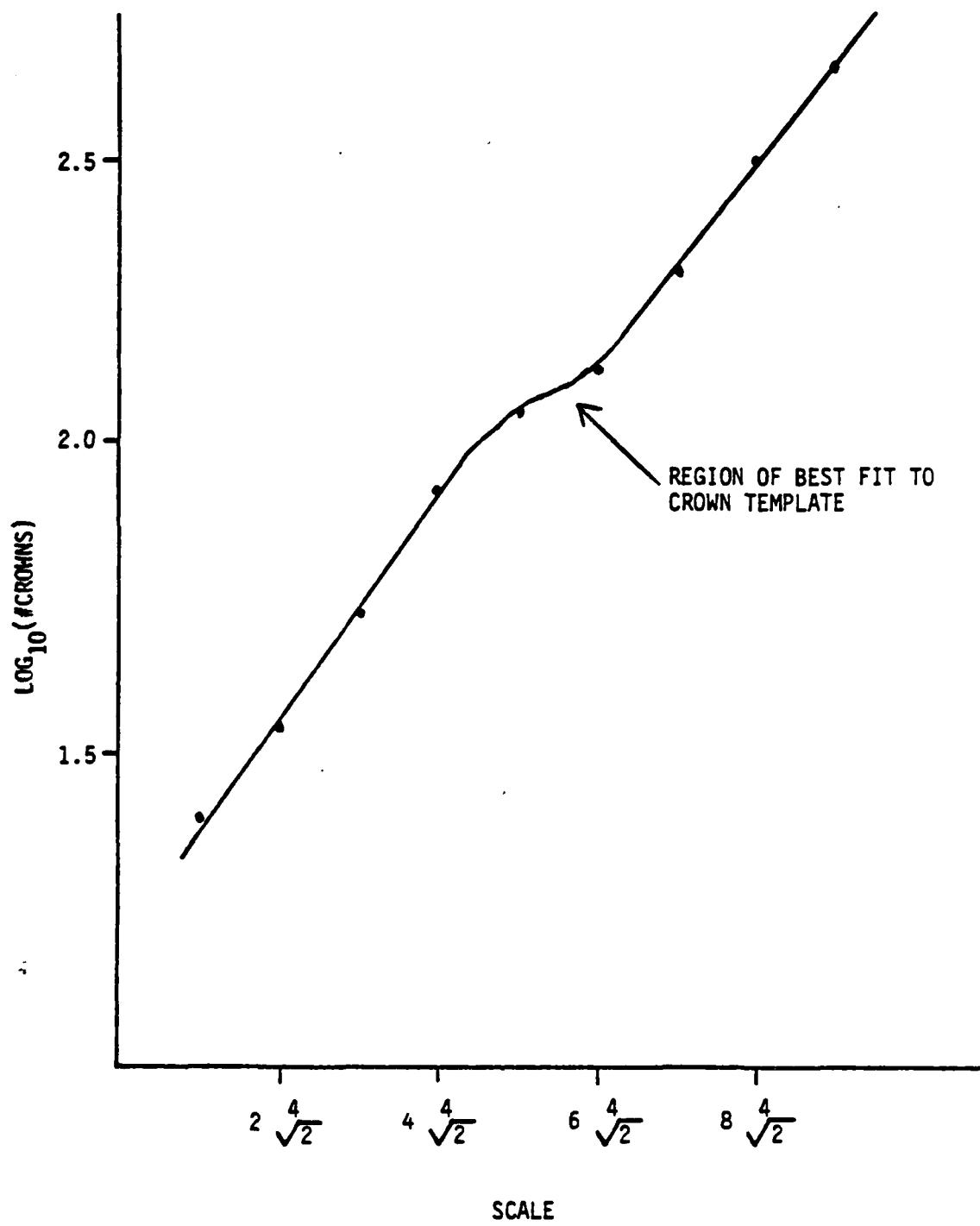
What is most apparent from the graph is that performance of the template is very sensitive to crown size scaling, too sensitive in fact to be used on anything but a uniform stand of forest. Lack of a more pronounced feature in the curve where the template "best fits" is to a great extent due to the variations in crown sizes within the test segment. A visual evaluation of the template output suggests that it is more effective than may be surmised from this graph. Crowns are counted almost perfectly in any uniform stand of forest, providing the image has proper scaling.

6. Locating Crowns in a Diverse Forest

In view of crown template scale sensitivity, applying such templates to real-world images with complex forest stands (e.g. images containing trees of various sizes) cannot be done directly. When applied to a diverse forest canopy, the 7×7 pixel operator performs satisfactorily for trees with crowns spanning 3-6 pixels. It generally misses trees smaller than two pixels in width, and erroneously counts the major branches of crowns more than 6 pixels wide as individual trees.

To address this problem, methods were investigated for sectioning forested areas into classes according to crown size. After sectioning, it becomes feasible to apply templates selectively to portions of the forest, each with the appropriate crown size.

A residential region in the Fort Belvoir/Woodbridge area scene (Figure 18) was chosen for study. Various stands of trees in the image have crowns ranging from 3-15 pixels in width. The range of these stands includes trees from newly-forested areas to mature shade trees.



CROWN COUNTING METHOD APPLIED
TO DIVERSE FOREST CANOPY

Figure 25. Crown Counting vs. Scale for Diverse Forest Canopy.

The forest was separated into regions of roughly uniform crown size using canopy texture as the criterion. First, the image was resampled at each of three scales in a manner which simulated lower resolution imagery. In each of the resampled images there was a crown size threshold below which individual crowns were not resolved. This resulted in a smooth appearance for sections of the canopy containing small trees. The lack of texture in portions of these reduced-resolution images becomes a useful characteristic for discrimination among crown sizes. Two methods were investigated. The first involves the five pixel min-max texture measure. (See Figure 37 and related text). For each scale, the derived texture image was smoothed and then density sliced into different forest classes. The second method, perhaps the more interesting, was to apply the crown template itself as the discriminator. The template creates a textureless output for sections containing unresolvable trees, and this allows easy size classification of trees in these areas. This method seemed to work slightly better than the min-max texture method.

The next step is to apply the crown template--blob counting method to both the original and to the reduced-scale images in the usual manner. Template output is then masked by the three *forest classes (different crown sizes) so as to extract crown information only from the sections of forest where scaled tree size matches the template size. Results are then combined to make a fairly accurate tree crown map of the entire image.

The overall crown extraction and counting procedure may now be summarized. Figure 26 presents the basic crown counting procedure. When a wide diversity of crown sizes are contained in the image, the variable-size crown mapping algorithm must be used to supplement the basic procedure. This is illustrated in Figure 27. Applying these procedures to the Fort Belvoir/Woodbridge scene, Figure 28 shows the outline of forested areas and the results of the multiscale crown-locating process. (The individual pixels within the forested areas correspond to tree crowns.)

*In the general case the number of forest classes (crown sizes) may be different than three.

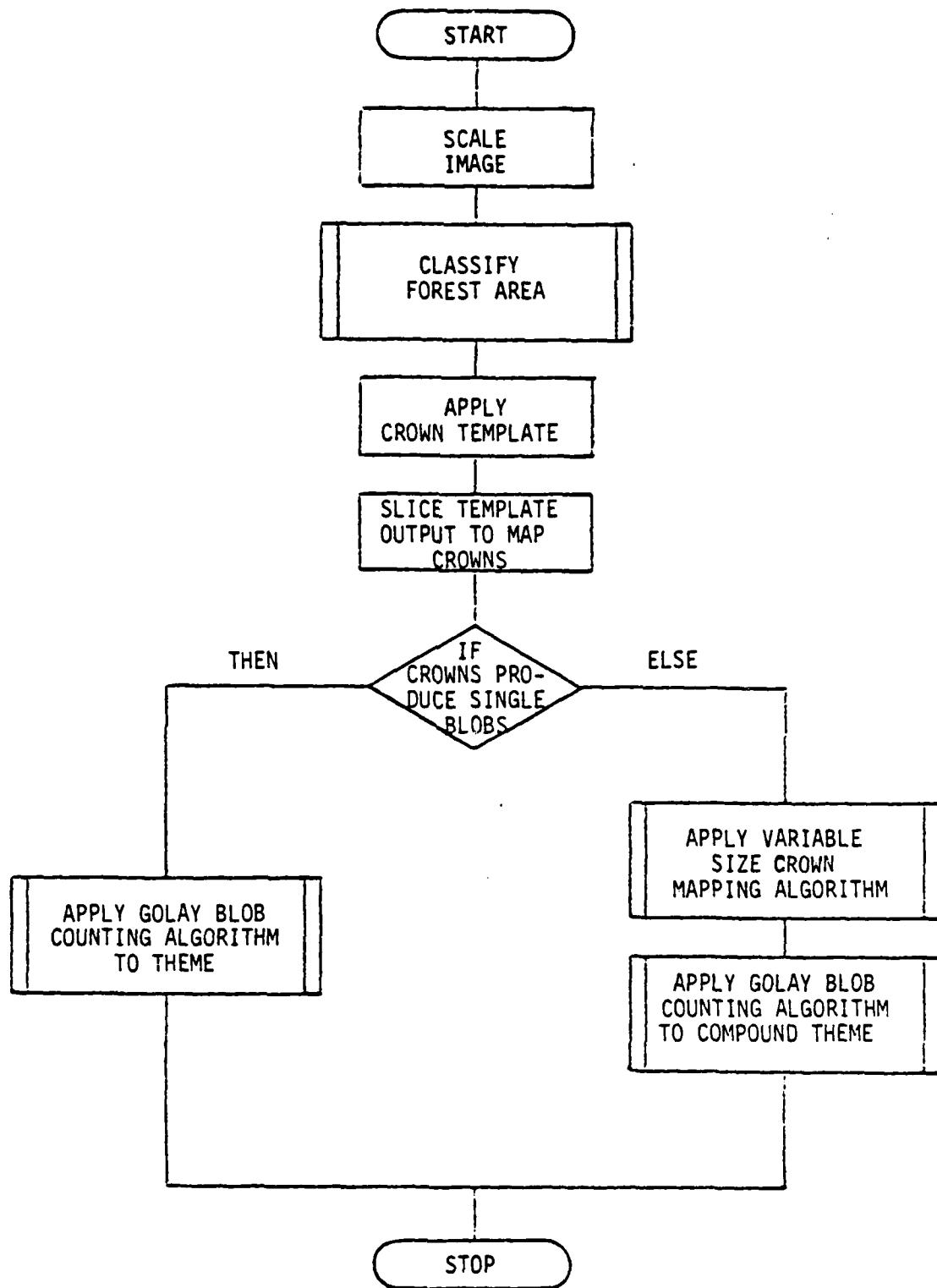


Figure 26. Crown Counting Procedure.

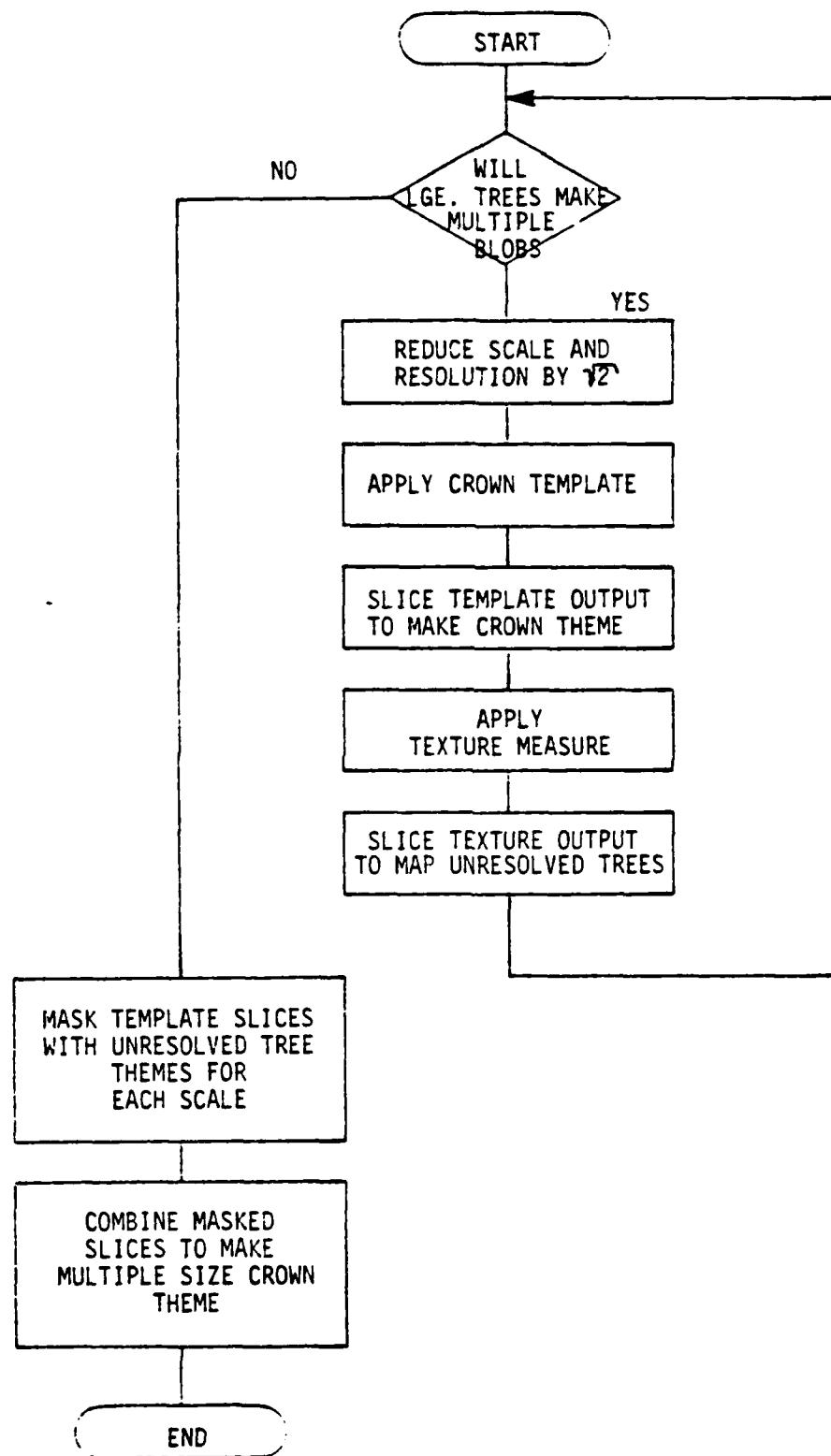


Figure 27. Variable-Size-Crown Mapping Algorithm.

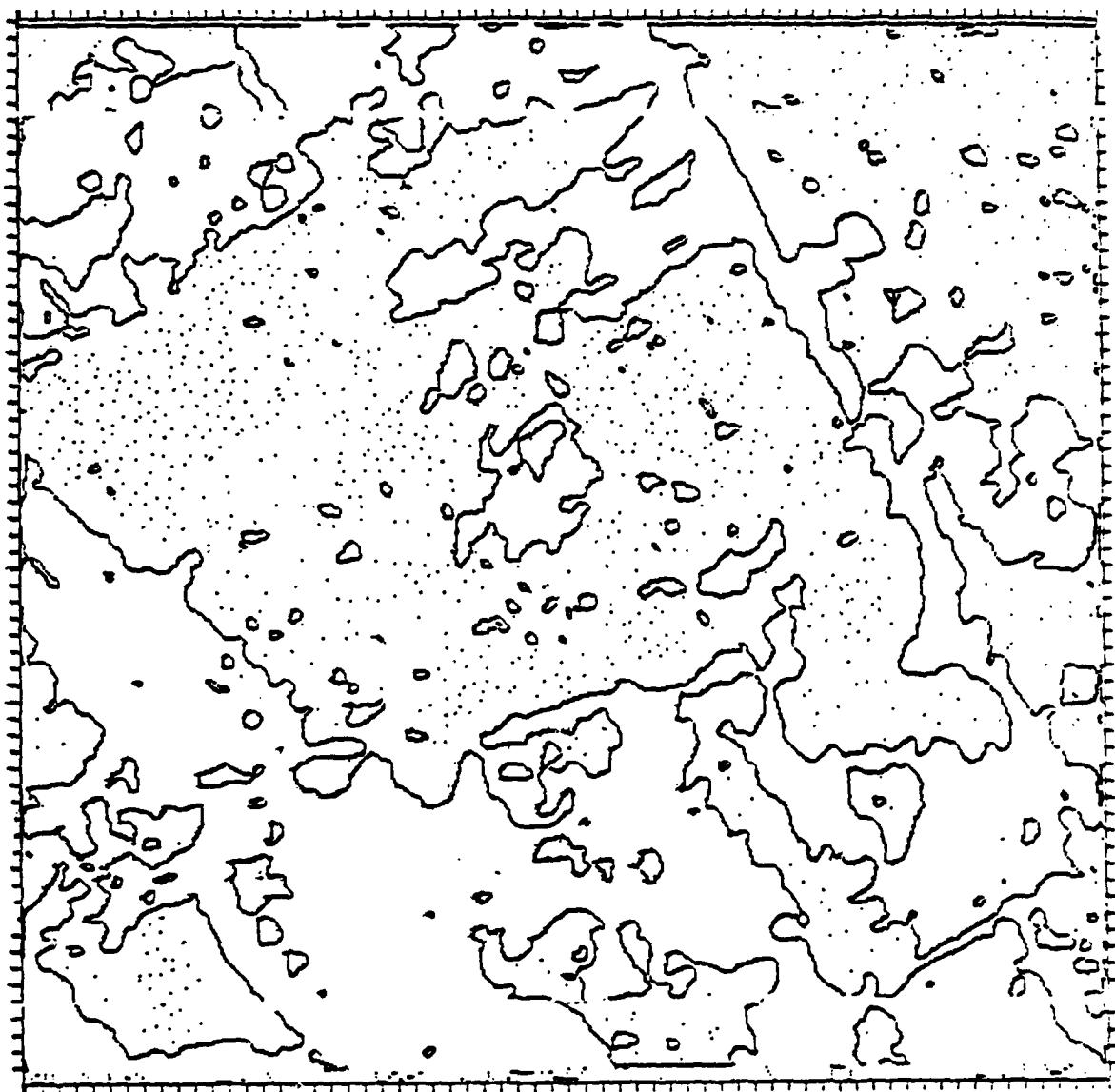


Figure 28. Extracted Crown Locations for Fort Belvoir/Woodbridge Subscene.

Figures 29, 30 and 31 show the canopy classification into three masks for the three crown sizes which were used in the process.

E. Extraction of Percent Canopy Closure

Generation of a digital gray-level map which depicts percent canopy closure by pixel intensity was performed on the digitized Fort Belvoir/Woodbridge image (see Figure 18 for the initial digital image). The map can be used to measure canopy closure at various points in the image. Or, the map can make possible the extraction of averaged values of percent canopy closure over operator-designated areas (e.g., factor overlays). The map will also be useful as an input to other canopy-related vegetation elements. A flow chart describing the procedure for extraction of percent canopy closure is shown in Figure 32.

The input required for canopy closure is the canopy theme previously discussed. In this particular image, non-canopy areas in the forest were of fine-detail and not easy to classify. Density slicing proved to be inadequate. Spatial characteristics were used to improve results by applying the five-pixel min-max texture measure and classifying jointly on the texture and the input image. The shadow areas were discriminated using a combination of low gray-levels and low texture values. The resulting canopy classification (total forest minus shadow areas) is shown in Figure 19.

Processing the theme into a canopy closure map begins by assigning canopy pixels (100% closure) to a 100% gray-level intensity value, and non-canopy pixels (zero closure) to an intensity level of zero. Next a wide-area moving average is performed on this two-level map. In the resulting image, intensity values for individual pixels then represent the percent closure over the area which was averaged. For this particular image a 0.1 hectare area (29x29 pixels) was chosen as a compromise between achieving adequate smoothing and retaining canopy detail. For other images the size of the moving-average operator may need to be adjusted to a different value.

For display purposes, and to reduce the canopy closure gray-level map to a form more suited to factor overlays, the map was sliced into five equal

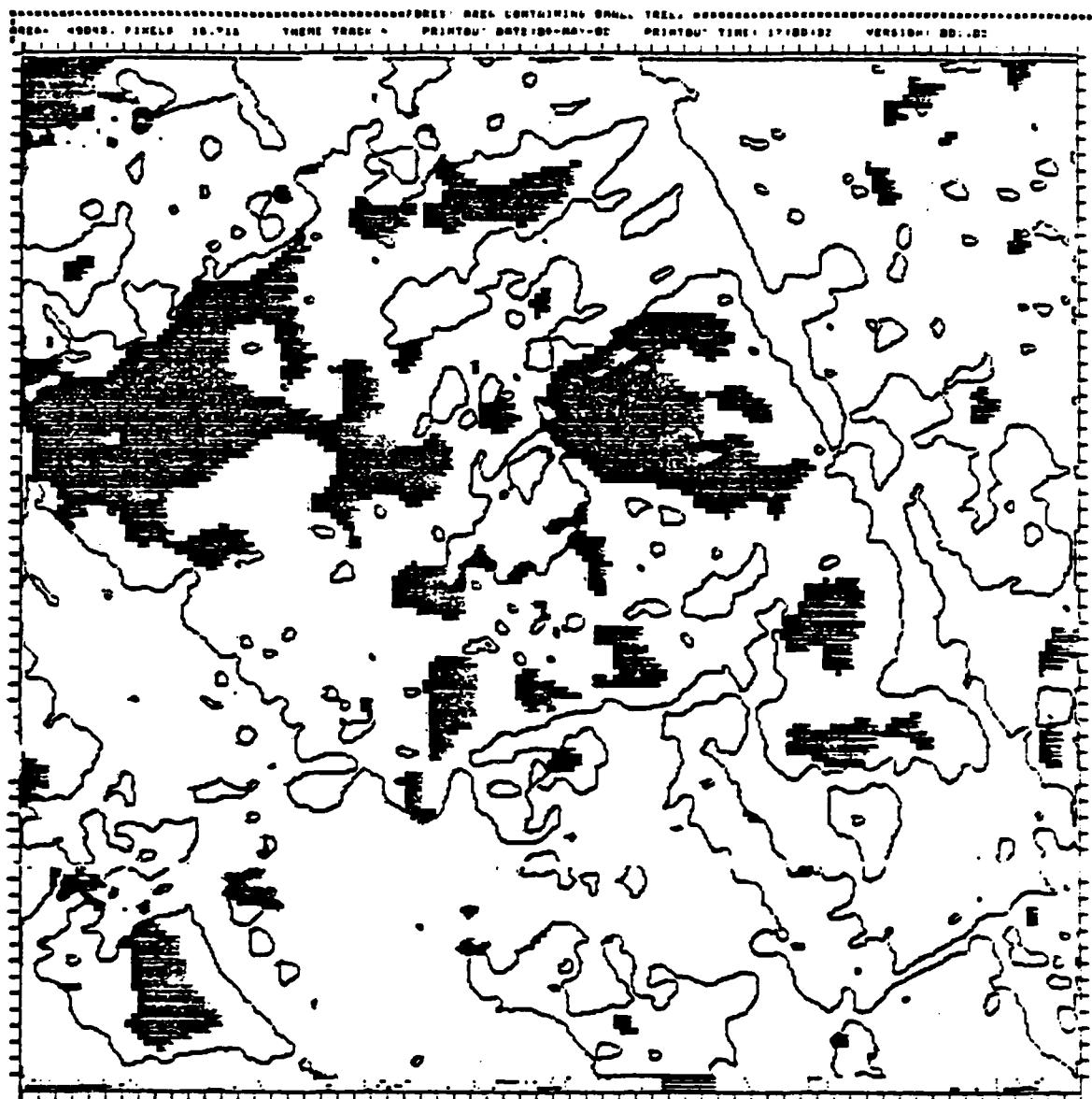


Figure 29. Forest Outline with Canopy Mask for Small Trees.

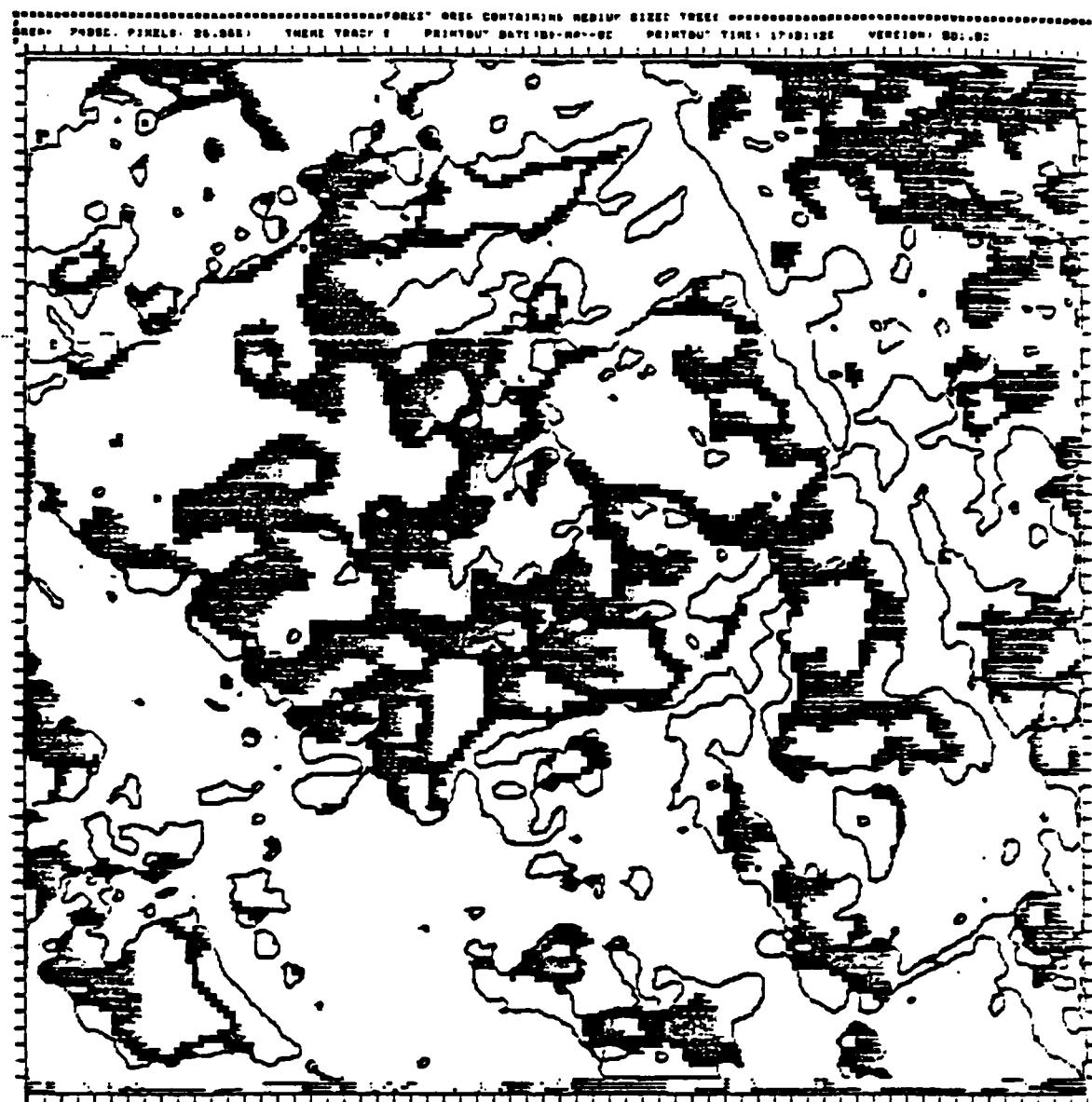


Figure 30. Forest Outline with Canopy Mask for Medium Trees.

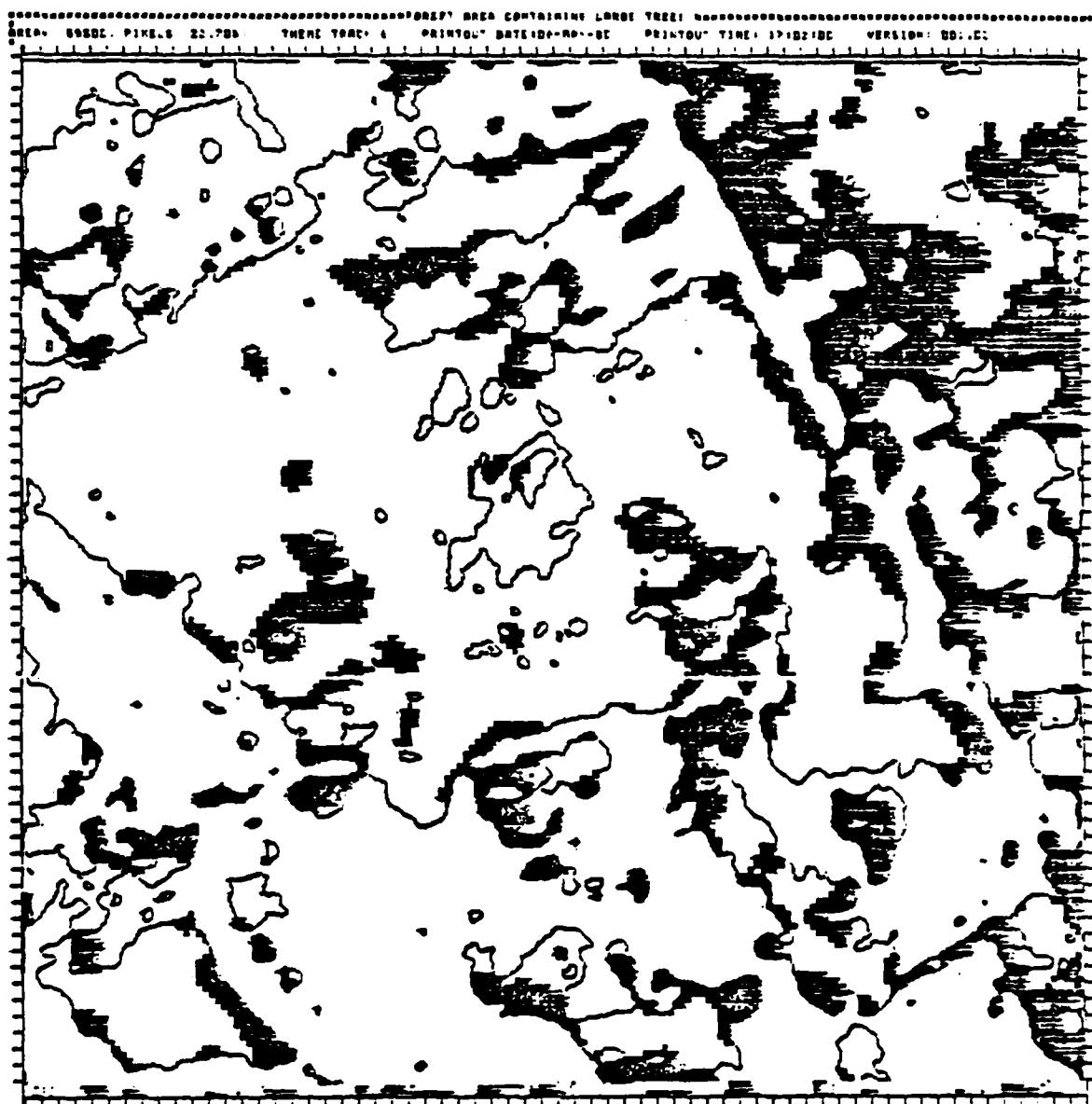


Figure 31. Forest Outline with Canopy Mask for Large Trees.

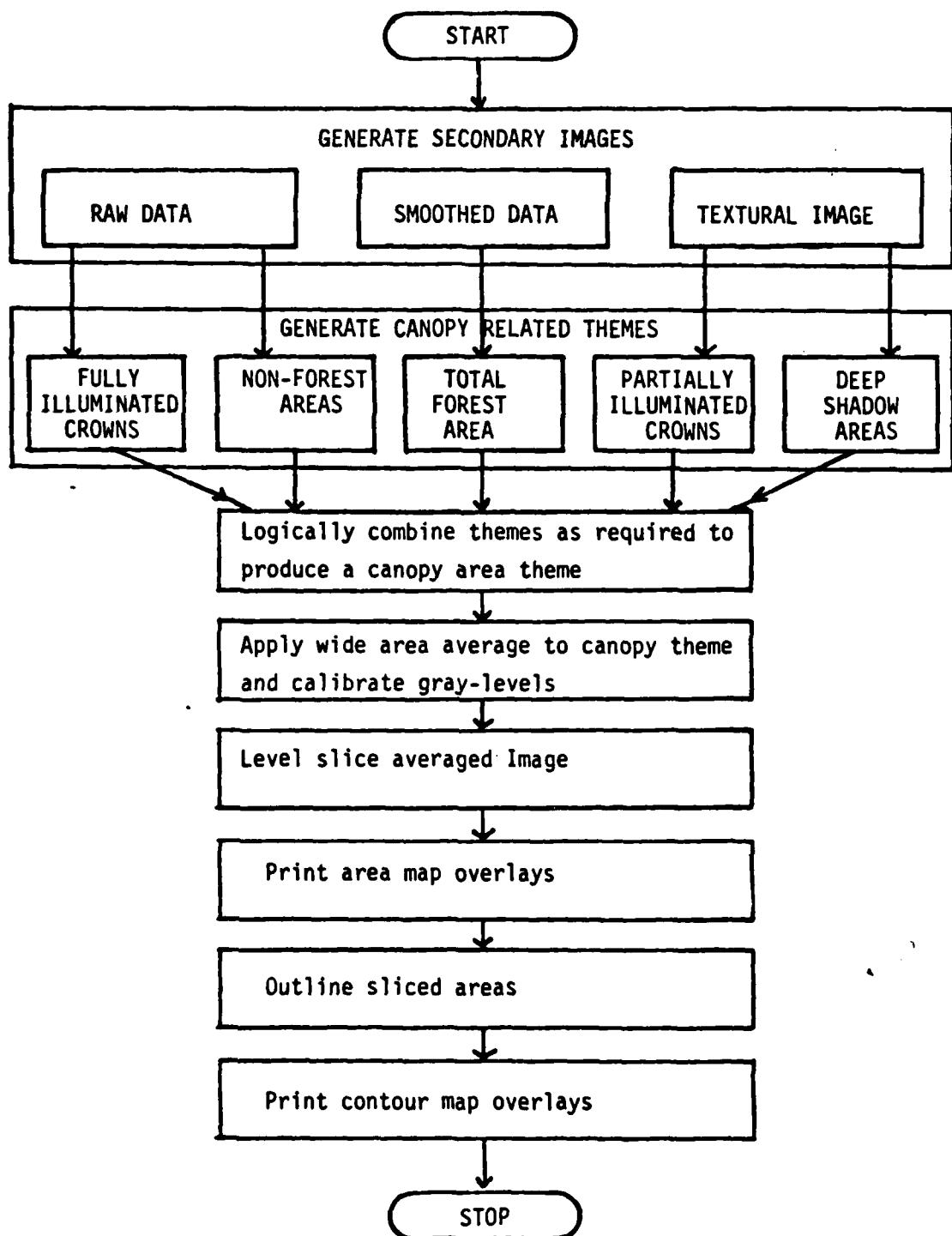


Figure 32. Procedure for Extraction of Percent Canopy Closure.

intensity intervals representing closure percentiles. The gray-level distribution of the digital map after averaging, and the position of the slices used, is shown in Figure 33. Also shown in the figure is a contour map of canopy closure, where contours represent the 80%, 60% and 40% closure levels and correspond to three of the slice locations in the histogram. The two thematic maps in Figure 34 are more easily interpreted. Each shows a canopy closure contour interval printed in solid black, with the total forest map printed in half-tone.

F. Extraction of Stems per Hectare

Determination of stem density is a direct fallout from a tree crown location theme. First, it is necessary for the analyst to have generated and modified as required an acceptable theme which locates individual tree crowns. It is also necessary that each crown in the theme have been reduced to a single pixel by application of an area-shrinking algorithm. Then, extracting stem density information is straightforward. The only requirement is to perform a wide-area moving average on the crown-locating theme. The intensity value of each pixel in the resulting gray-level image is proportional to the number of stems in the surrounding averaged area. Calibration of the resulting gray scale in stems/hectare (or other appropriate units) can be accomplished by mapping the input theme to a specific gray-level prior to taking the average. The level is determined by the areal size of the moving average and by the desired output calibration units.

Figure 35 is a flow chart describing the extraction procedure, and a pictorial example of the procedure is shown in Figure 36. At the top in Figure 36 is the original image with the crown theme (individual pixels) superimposed in white. The lower image is the result of a 0.1 hectare (29x29 pixel) average of the crown theme, and local brightness in this image is proportional to stems per hectare.

As with percent canopy closure, crown density can be displayed or extracted from the new image in several ways. It can be contoured or density sliced. It can be read either at individual points to extract local averages, or, if desired, larger areas such as defined by a forest overlay can be examined by using histogram-generating software.

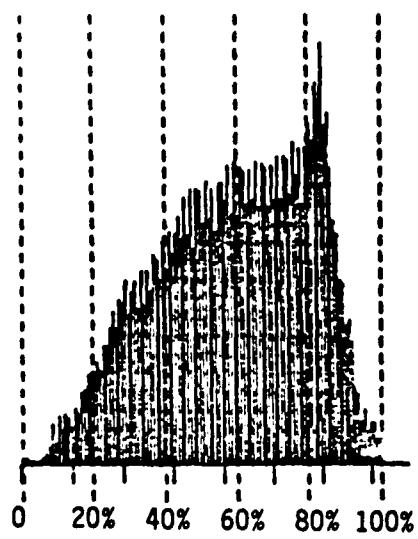
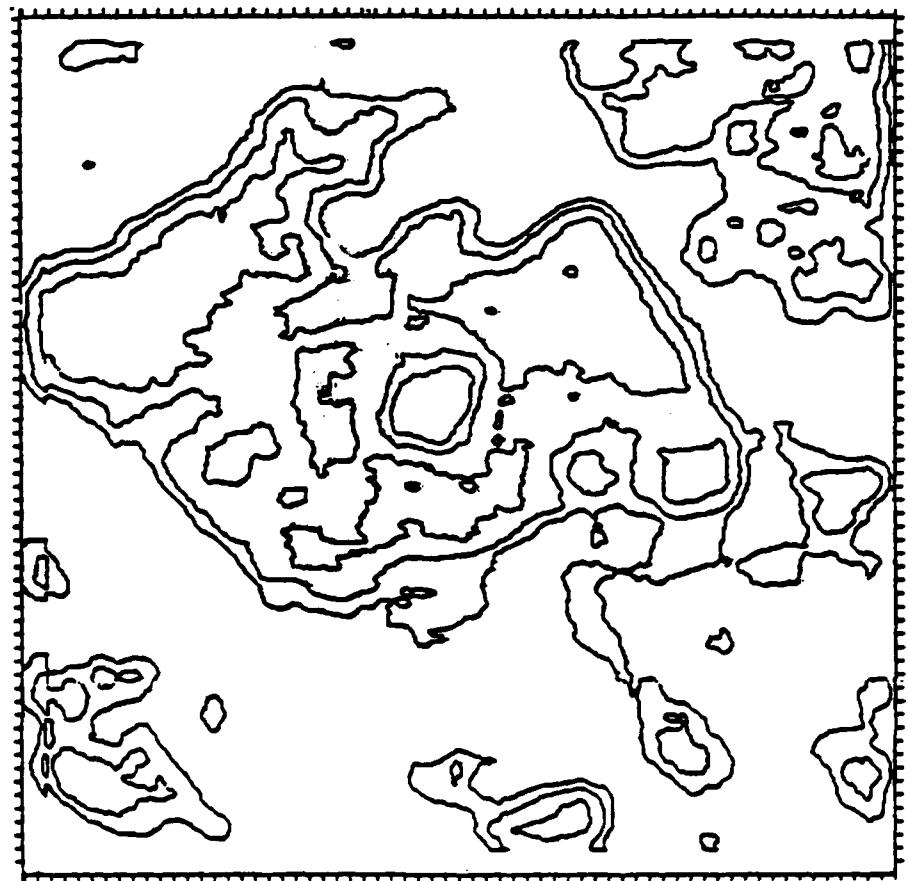


Figure 33. Canopy Closure Contours (Top), and Histogram of Gray-Level Closure Map (Bottom).

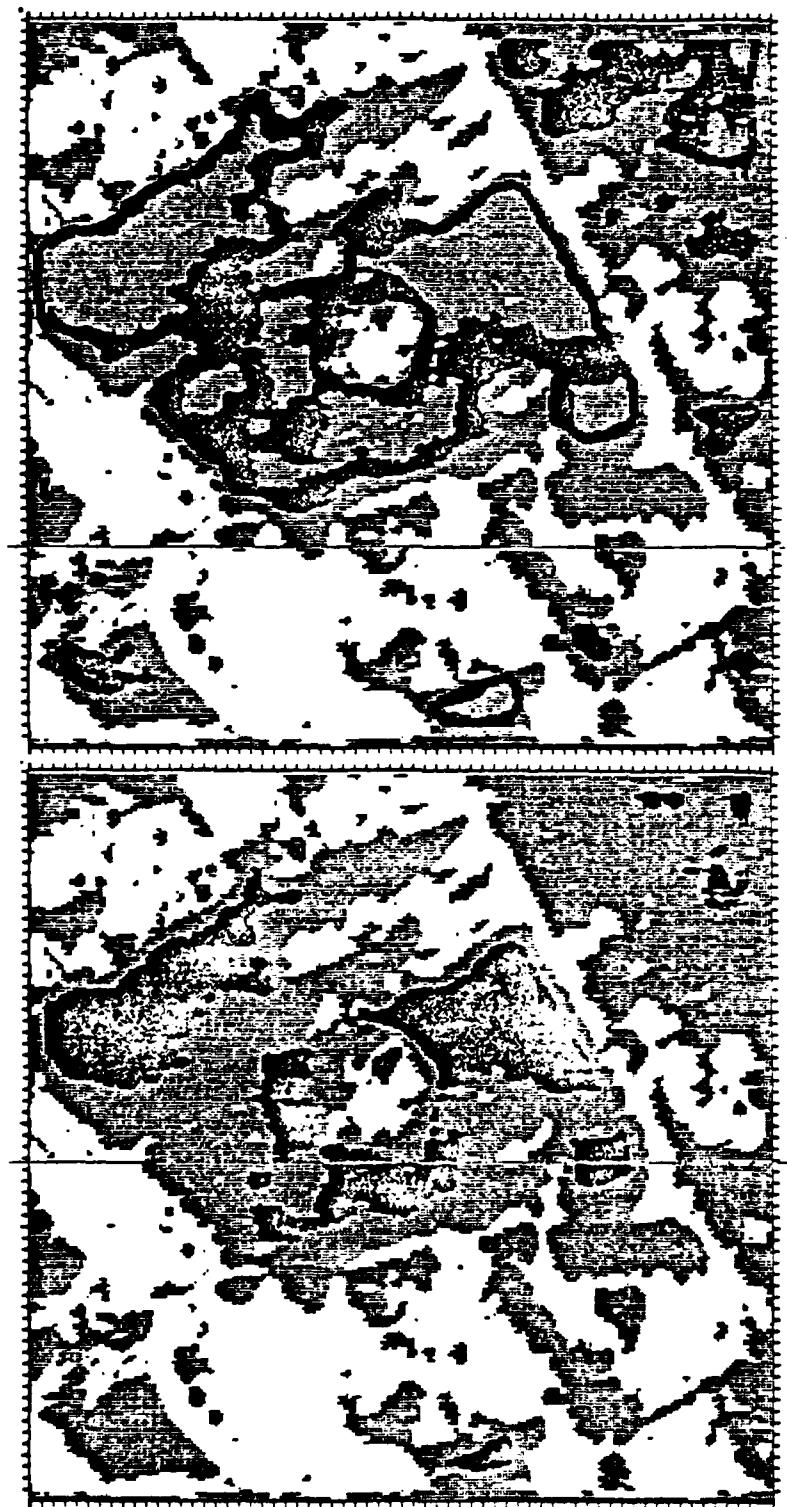


Figure 34. Canopy Closure Intervals: 60-80% (Top, Black)
and 80-100% (Bottom, Black). (Forest Theme in Gray.)

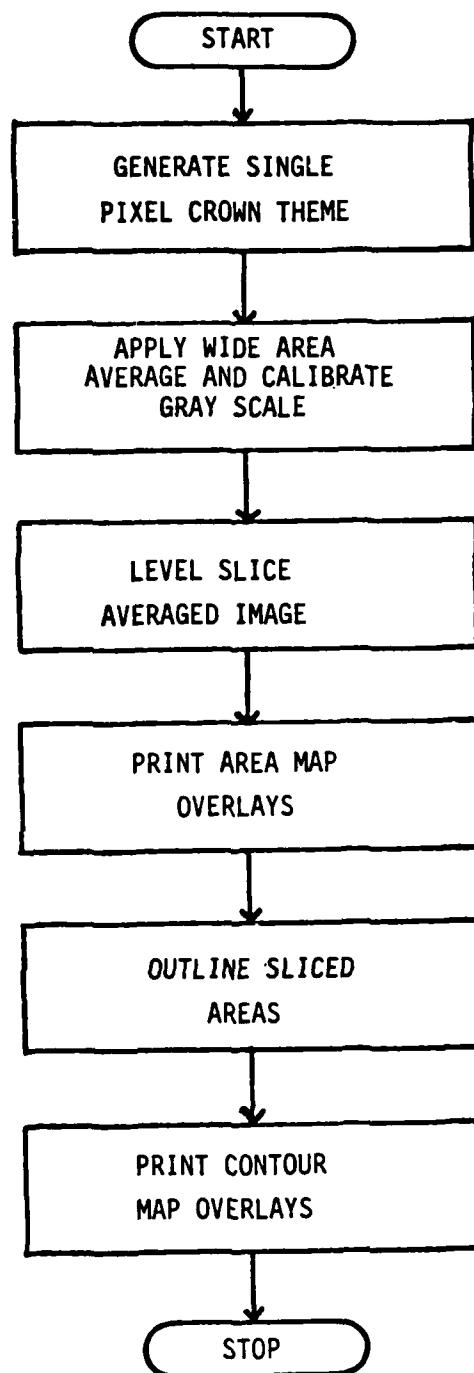


Figure 35. Procedure for Extraction of Stems per Hectare.

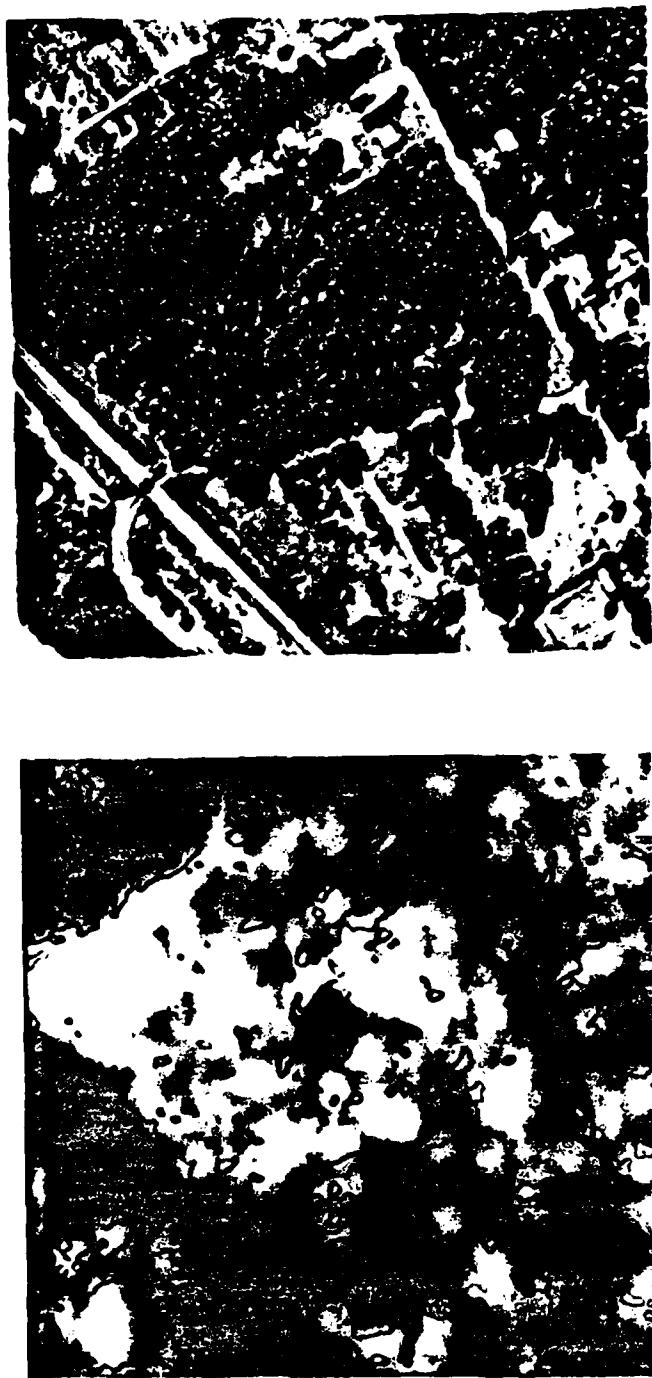


Figure 36. Stems Per Hectare:
Original Image With Crown Theme (Top), and
Gray-Level Stem Density Map (Bottom)

IV. Mensuration*

Several of the terrain elements require the measurement of elevation, distance, or area using digitized aerial imagery. This is performed either by direct operator interaction using a cursor, as in the case of determining height, or automatically, as in computer calculations of stems per hectare. GE DIAL image mensuration methods, commonly used on Landsat data, were adapted for use with digitized imagery. Techniques were generalized to meet the requirements of all imagery used in this study. The program stores, via operator input, the parameters necessary to fully define the viewing geometry of stereo pairs or scanner images. The following is a typical GE DIAL terminal display after parameters have been entered.

Vertical Photo Parameters

Camera Focal Length	=	0.153 Meters
Platform Altitude	=	2100 Meters
Digital Resolution	=	1.08 Meters/Sample
Digital Resolution	=	1.08 Meters/Line
Principal Point Chan 1	=	(1420, 339)
Principal Point Chan 2	=	(214, 446)
Principal Point Chan 3	=	(1399, 474)
Principal Point Chan 4	=	(xxxx, 0)
Solar Altitude	=	37 degrees
Solar Azimuth	=	135 degrees

The parameters are then used as necessary to perform measurements of distance, height, area and parallax as described in the procedural guide for vegetation. For example, canopy height can be ascertained by any of three methods: shadow length; visible base; or parallax differences. Measurement is fairly rapid and, after initial parameter set-up, eliminates the possibility of human calculation error. The mensuration menu presented to the analyst is as follows:

*The mensuration capabilities enabled and demonstrated during this phase of the study were confined to the basic needs of the analyst. This part of the effort was not meant to duplicate capabilities now existing in automatic analog and/or digital analytical photogrammetric plotter systems.

Mensuration Menu

- (1) Aerial Photo Parameter Set-Up
- (2) Distance Measurement
- (3) Calculate Solar Position
- (4) Object Height from Shadow
- (5) Object Height from Parallax
- (6) Object Height from Visible Base Option

The most notable feature of the program is the method for locating image features. After the operator grossly locates the section of interest in the digital scene via positioning a cross-hair cursor, a small window containing a 4X enlargement of the surrounding area is inserted into the display. Repositioning the cursor within this window locates the feature to subpixel accuracy.

In addition to minimizing the possibility of human error, interactive mensuration provides the potential of another useful feature which has not been implemented. Based on the geometry of any particular measurement, the computer can quickly and rigorously calculate the expected error and warn the analyst of measurements with a high uncertainty. Such calculations are generally too long and complex to be performed during routine manual interpretations.

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INTERACTIVE DIGITAL IMAGE PROCESSING FOR TERRAIN DATA EXTRACTION-ETC(U)
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V. Vegetation/Land Cover Boundary Extraction

A. Objective and General Approach

Vegetation boundaries are one of the 13 vegetation data elements to be extracted from aerial imagery. In addition, the process of extracting boundaries for one particular vegetation class, forest, yields a digital forest mask which is required in the extraction of several forest-related vegetation data elements.

The end product of vegetation boundary extraction is a vegetation boundary factor overlay. This factor overlay must be suitably annotated, of course, and it normally will be produced at a scale of 1:50,000 to be compatible with standard military maps.

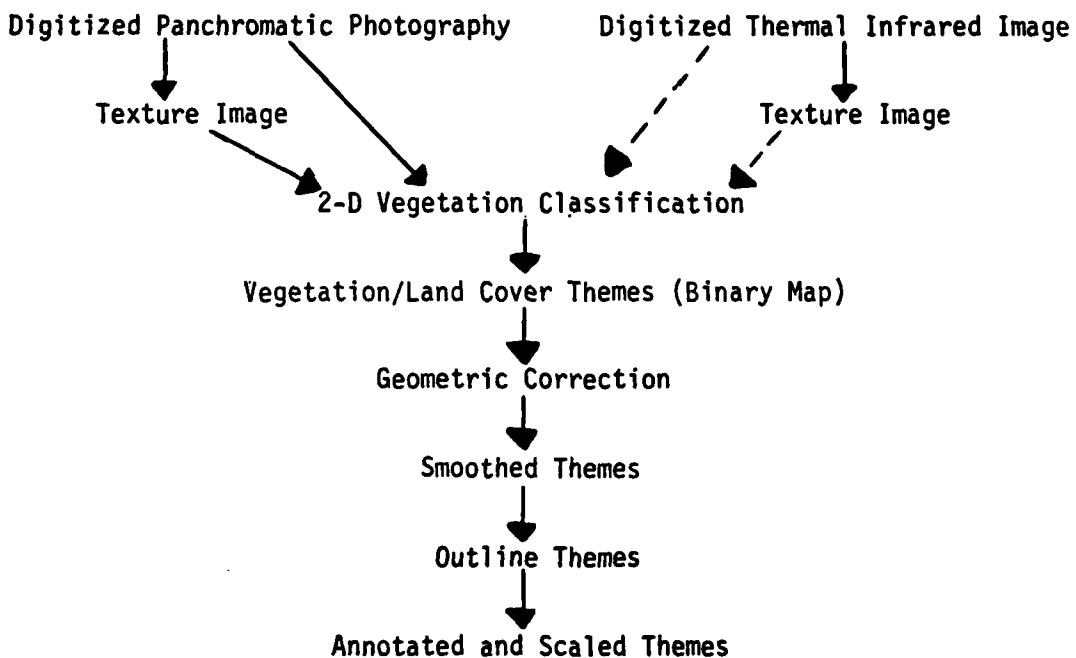
A digital forest boundary (or any vegetation boundary) is produced from a digital theme or binary map in which each picture element is either a "one" or a "zero" depending on whether the digital classification procedure determines there is forest at that picture element location. For the imagery which has been considered in this study, a general characteristic of the digitally produced vegetation themes emerges: The themes, particularly the forest theme, tend to have a high degree of fine structure associated with them. That is, an overall forest area theme will exhibit many small regions (only a few pixels each) which are actually forest, and these are interspersed with many other similar small regions which are not forest. This is probably an accurate representation of the real scene, but it leads to vegetation outlines and factor overlays which are undesirably complex. To avoid this problem, techniques for smoothing the digital image data are incorporated in various steps in the extraction procedure as may be required by the conditions pertaining to each analysis. This will be referenced or discussed in subsequent paragraphs describing more fully the vegetation boundary extraction procedure and its application.

Based on the imagery available and selected for this study, the approach to vegetation boundary extraction has been oriented to a process having an input consisting primarily of panchromatic photography (or imagery which simulates panchromatic photography). If the proper results can be achieved

using imagery of a single type, this is considered to be a desirable goal. It has been found, however, that some cases arise in which panchromatic photography is not a sufficient input to enable extraction of all desired vegetation boundaries with high quality. The use of thermal infrared imagery as a supplemental input was found to resolve the problem for these cases.

For virtually all vegetation boundary extraction, using panchromatic photography alone or supplemented, a key processing step is the derivation of a texture image from the digital input image. This process will be described in subsequent paragraphs pertaining to the detailed procedures for vegetation boundary extraction.

The general procedure which has been developed for vegetation boundary extraction may now be listed as follows:



Further discussion of this procedure, including a few additional steps which have been omitted here for purposes of simplicity, is contained in section V. B. which follows.

B. Description of Steps in the Procedure

1. Pre-Processing the Input Image

The starting point in the extraction procedure is assumed here to be an image in digital form, i.e., an image spatially and radiometrically quantized and digitally encoded on magnetic tape or other medium. Each digital image will have been derived from a single sensor (side-looking radar, thermal infrared scanner, or panchromatic camera). While the characteristics of the sensors and the manner in which their outputs are digitized can occur in many forms, it will be assumed here that digitized picture elements (pixels) of the input image will have an adequate range of possible intensity values but may, from image to image, pertain to different sized elemental areas on the ground, i.e., 3 ft. x 3 ft., 10 ft. x 10 ft., etc.

Pixel linear dimensions in the scene having values in the range of 8-20 feet appear to be most useful for vegetation boundary extraction, assuming inherent image resolution is comparable to or better than the pixel size. Larger-sized pixels tend to become too gross for the extraction procedure and produce a poorer quality output product. Smaller-sized pixels generally will present too much information for boundary extraction** and usually will not provide a good match with the texture operator used in the procedure. When the pixels are too large, the extraction operation merely accepts the input image data and produces the best possible vegetation boundary themes. When the pixels are too small, a pre-processing step is incorporated which converts the input image data to a more gross resolution and scale in which there are fewer total pixels and a correspondingly larger pixel size (as is desired for the remainder of the vegetation boundary extraction process).

If, for example, the pre-processing operation is to convert the input image data from 3 ft. x 3 ft. pixels to data with 9 ft. x 9 ft. pixels, two steps are involved:

- (a) Apply a 3x3 moving average operator* to the input image.

** Smaller-sized pixels are necessary, however, for tree crown extraction.

* A 9-pixel averaging operator in a 3x3 square array.

(b) For the output image of (a), sample every 3rd pixel and every 3rd line. The result of this step will be a new digital image which will become the input image for the remainder of the vegetation boundary extraction process.

If the pre-processing is required to convert from 2 ft. x 2 ft. pixels to 10 ft. x 10 ft. pixels, a 5x5 moving average operator, and sampling every 5th pixel and line would be used. Other conversion ratios are handled similarly, except that non-integer ratios are not handled as easily and were not accommodated in this study.

When the digital image has the proper scale (pixels per mile, or pixel size) for boundary extraction processing, whether or not that scale was achieved via pixel size conversion as just described, image smoothing is sometimes a desirable pre-processing step prior to the boundary extraction. In such situations a light smoothing operation, perhaps using a 2x2 pixel averaging operator, is used. Heavier smoothing can aid in producing more homogeneous vegetation themes, but it also leads to classification problems at vegetation boundaries. This is noted in the subsequent discussion of applications of the boundary extraction procedure.

2. Texture Processing

Working with panchromatic aerial photography it becomes apparent almost immediately that density slicing alone will not provide clear separations of the various vegetation/land cover classes. Many of the classes have similar or overlapping density ranges in the imagery. The approach taken, therefore, was to use spatial properties of the image, specifically texture, to assist in the discrimination. An absolute Laplacian texture measure, and a min-max texture measure were investigated.

A texture measure that can be implemented with image convolution is the absolute value of the output of a Laplacian operator. This operator is the bi-directional second derivative of image intensity. Its effect on an image is to make image discontinuities appear sharper than they actually are. The output of a Laplacian operator has a mean value of zero, and zero output occurs at those points where no edges are found. When the operator

passes over an edge of increasing intensity the output shifts first positive, then negative. When extracting texture, one is more interested in the number or density of image discontinuities than in exaggerating edges, so the Laplacian operator output is rectified. Any discontinuity then results in two positive swings in the output. Subsequent smoothing of the rectified output results in an image with intensity roughly proportional to the number and magnitude of discontinuities in the original image.

The second texture measure implemented involves applying a small moving operator which examines segments or neighborhoods within an image and extracts a measure of brightness variability within each neighborhood. An output image is formed by changing the intensity of the center picture element of each neighborhood to a value corresponding to the difference between the maximum and minimum brightness values found in that neighborhood.

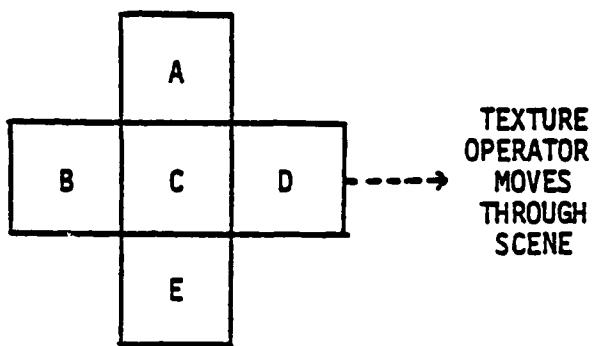
Three neighborhood sizes and patterns were incorporated into the program, allowing the analyst to select the configuration most suited to a particular image: a 3x3 square window; a five-pixel cross pattern, and 3 pixels in a row. The min-max texture measure involving a five-pixel cross pattern appeared to be preferable for most applications. This texture operator is illustrated in Figure 37.

Texture measures of the types implemented are very "noisy" and will create extremely "ragged" mappings containing a multitude of holes. Severe filtering of the output from these measures creates large uniform areas with gray-levels proportional to texture, and the effects of small individual edges are removed. After experimenting with several filters, a simple moving average applied to a 7x7 pixel neighborhood was found suitable for most requirements. Sequential applications of the filter provide a means for simulating much larger filters when severe filtering is needed. The 7x7 Moving Average operator is shown in Figure 38.

Examples of texture images, smoothed and unsmoothed, will be found in sections V. C and V. D pertaining to application of the vegetation boundary extraction procedure.

3. Panchromatic Photography Supplemented by Thermal Imagery

As noted previously, some situations require digital inputs to the classif-



$$\begin{bmatrix} \text{TEXTURE VALUE} \\ \text{AT LOCATION C} \end{bmatrix} = \begin{bmatrix} \text{INTENSITY OF} \\ \text{BRIGHTEST} \\ \text{PIXEL AT} \\ \text{A, B, C, D, E} \end{bmatrix} - \begin{bmatrix} \text{INTENSITY OF} \\ \text{DARKEST} \\ \text{PIXEL AT} \\ \text{A, B, C, D, E} \end{bmatrix}$$

Figure 37. 5-Pixel Min-Max Texture Operator.

	0.016	0.024	0.024	0.024	0.016	
0.016	0.024	0.024	0.024	0.024	0.024	0.016
0.024	0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024	0.024
0.016	0.024	0.024	0.024	0.024	0.024	0.016
	0.016	0.024	0.024	0.024	0.016	

— — — →
OPERATOR
MOVES
THROUGH
SCENE

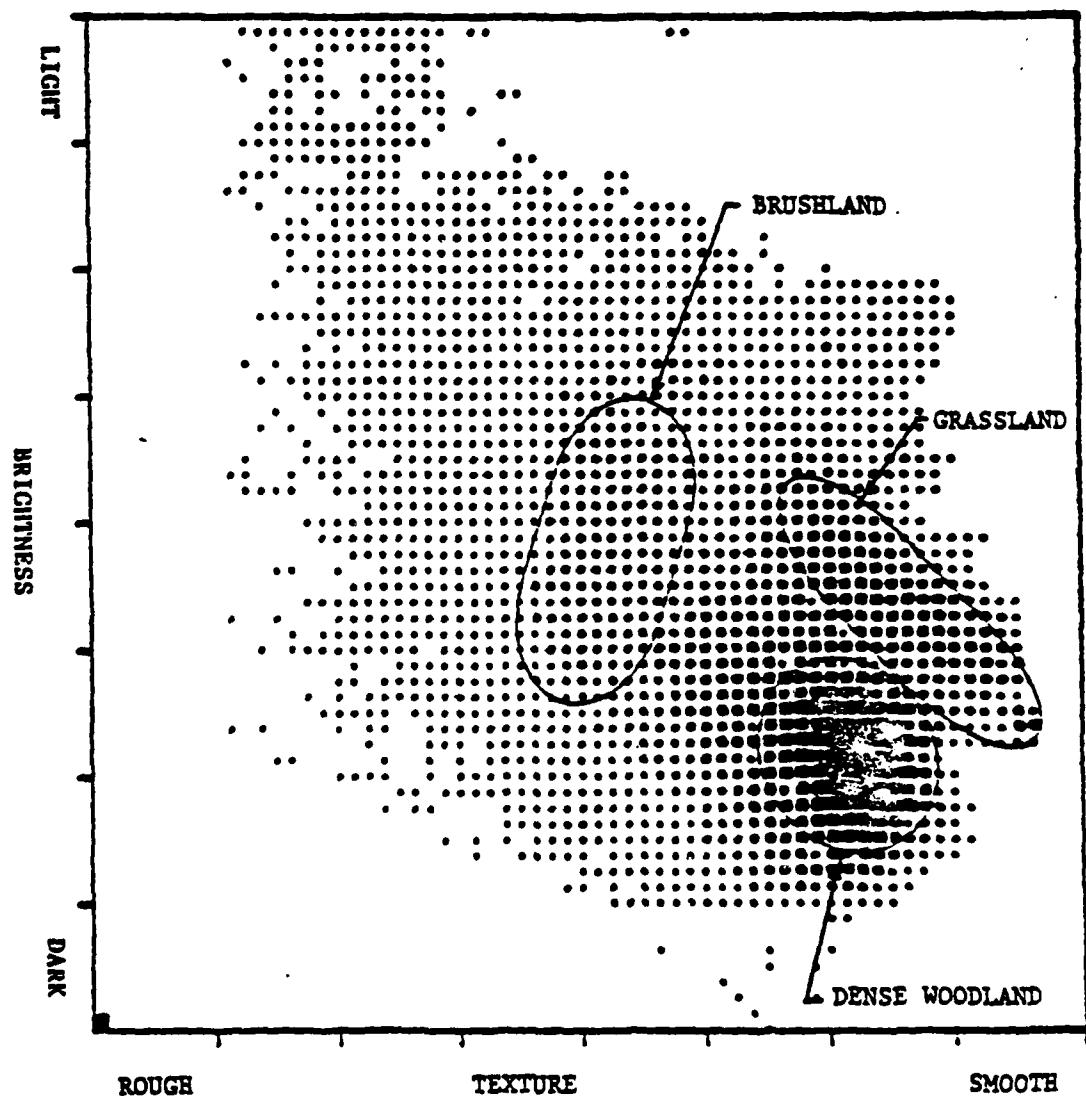
Figure 38. 7x7 Smoothing Operator.

ication process from both photographic and thermal imagery of the same scene. When this is necessary, both digital images must be in registration at some appropriate point in the procedure prior to production of the factor overlay. In this study the situations requiring multiple sensor inputs actually involved the use of two channels of multispectral scanner data. The channel data were in registration, and thus no further registration processing was necessary. If multispectral scanner data is not used, as will be the case generally in accordance with the study requirements, then a digital registration operation normally will be necessary. This is accomplished in the geometric correction process which follows classification. It is presumed, however, that the scales of the two input images are, or will be made similar, prior to being digitized. It is to be noted also that performing the registration operation after classification implies that image data from two sources are not used jointly in the classification process. This has proved to be the case except in one instance in which spatial resolution was quite gross (approximately 40 feet). In that situation digitized panchromatic photography and thermal imagery were employed jointly during classification and thus were required to be in registration.

4. Classification

The classification operation is an interactive digital activity in which each pixel in the scene is assigned to one of a predetermined number of vegetation/land cover classes (e.g., forest, grassland, water, etc.). All pixels assigned to a particular class, such as "forest," are output from the classification operation in their proper geometric locations as a forest binary map or theme. Examples of such themes may be found in the vegetation boundary extraction applications which follow.

The classification operation (which, in the GE DIAL system, has proven to be highly efficient) begins by producing and displaying to the analyst a two-dimensional histogram or scatter diagram. This is illustrated in Figure 39, which is a scatter diagram of image brightness vs. image texture. Each location in the diagram represents a particular combination of these two variables, and spot size in the diagram is proportional to



SCATTER DIAGRAM OF IMAGE BRIGHTNESS VS.
MAX-MIN TEXTURE MEASURE FOR PA. TEST SITE

Figure 40

the number of pixels exhibiting each combination. In general, the input image and the derived texture image which produce such a scatter diagram may or may not have been smoothed. In the illustration, the texture image has been smoothed and also has been inverted (high texture areas are displayed with low intensity). The two main pixel concentrations or clusters in the diagram illustrated represent forest and grassland. It is apparent that these clusters cannot be separated by slicing image brightness only. However, the clusters are separable via two-dimensional slicing.

The analyst's task here is to establish one or more rectangular decision boundaries or partitions around each group of pixels in the scatter diagram such that the vegetation or land cover features in the image are optimally separated. After each attempt at partitioning, he observes the resulting themes on an image display, and he makes partition corrections using his judgment and his knowledge of the scene. He iterates this interactive process until satisfied that he has extracted themes having the desired quality.

Typical thematic maps and scatter diagrams are illustrated in the applications of the vegetation boundary extraction procedure which follow. The same general procedure is used for classification based on (1) a digitized panchromatic photographic image and its derived texture image, or on (2) a digital thermal image and its derived texture image.

5. Geometric Correction

Factor overlays are intended to overlay and register with standard military maps. In general, the digital image data from which vegetation boundary factor overlays are produced must be subjected to a geometric correction operation to enable registration to a map. This correction is performed most appropriately on the vegetation/land cover themes or binary maps. Procedures for using control points in the binary image and map, are in common usage and will not be discussed here. One such procedure exists in the GE DIAL system, but it was not used in this study. (Some aspect correction, a form of geometric correction which compensates for aircraft scanner rectangular pixels, was employed and was implemented via omitting or replicating appropriate pixels and lines).

If image data from two sensors (e.g., panchromatic photography and thermal imagery) are used in the classification process, such data are used independently and not jointly. That is, digitized panchromatic photography and its texture image might be employed to produce the grass-land theme, while the digital thermal image and its texture version might be employed in a separate operation to produce the water theme. The grassland and water themes, therefore, will not be in registration during the classification process, but they become registered to each other at the time each is registered to the same map.

6. Theme Smoothing

In spite of all the attention given to image data smoothing prior to classification, invariably the resulting vegetation/land cover themes will contain too much fine structure for purposes of a factor overlay. Accordingly, the themes are subjected to a smoothing process involving a moving operator. However, the logic differs from that for smoothing a digital multi-gray-level image. The smoothed theme must remain binary in content. In this study the Golay theme processor often was employed. However, other techniques were tried also, and further investigation is necessary to develop or establish the most suitable theme smoothing procedures.

The Golay processor has numerous options and involves a moving operator which examines six of the eight pixels surrounding a particular theme pixel and resets that pixel to a "one" or a "zero" depending on the 6-pixel surround pattern that it measures. In the "Fill" option, if the moving operator senses a "zero" surrounded by "ones", the center pixel is changed to a "one". This is used to fill holes in a theme.

There are other options such as "Shrink" which will remove single, isolated pixels in the theme, and "Swell" which will smooth the edges of a theme with a very irregular border.

A theme which pertains to bare or highly reflective areas of the scene often will contain roads. When this theme is smoothed, the roads (which are usually only a few pixels wide) disappear. To avoid loss of these important features in the data, the analyst produces the roads as separate themes

which are not subjected to smoothing. He proceeds similarly for other important narrow themes such as watercourses.

Depending upon the particular details of smoothing for the input digital image, for the texture image and for the vegetation/land cover themes, there can be gaps or overlaps at the boundaries of geographically adjacent themes. This is a matter requiring attention in order to avoid inaccuracies in the resulting vegetation boundary factor overlay. It was resolved in the present study, but other techniques need to be investigated in order to establish the most suitable procedure.

7. Outline Themes

When all the desired vegetation/land cover themes have been produced and properly smoothed, the themes are subjected to an edging or outlining operation. The result is a new set of themes which are each merely the edge or border pixels of the original smoothed themes. To achieve the theme outlining, another option of the Golay theme processor is used - the "Edge" option.

8. Theme Annotation

Each outline theme pertains to a contiguous area of a particular vegetation/land-cover class. These themes next must be digitally annotated with such information (in alphanumeric code) as map unit identification, vegetation type, mean height to top of canopy, and maximum canopy closure in percent. The techniques for annotation are relatively straightforward and well within the state-of-the-art. (A capability exists in the GE DIAL system, although it would require some changes to operate efficiently for the application here). In any event, no attention was directed to this process in the present study other than to annotate a few outline themes in a digital, brute force manner in order to establish feasibility and the general appearance of the final outline theme.

9. Vegetation/Land Cover Boundary Map

The annotated outline themes are now digitally combined to form one binary vegetation/land-cover boundary map. Two options are then available to produce a hard copy from the digital data: The map may be output on a printer with a graphics capability (GE DIAL uses a Gould 5000 electrostatic

printer) or the map may be recorded on film using a digital image film recorder (GE DIAL uses a Dicomod D47 recorder). These output products are essentially the desired vegetation boundary factor overlay, except that they usually are not at the 1:50,000 scale. To achieve the desired scale, the map produced via the printer is photographed and then photographically reduced to a scale of 1:50,000. Similarly, the map recorded on film is photographically enlarged to the proper scale.

C. Application of the Boundary Extraction Procedure

1. Fort Belvoir/Woodbridge Scene

The three digitized images (Figures 9, 10 and 11) were saved on DIAL's mass storage disk for quick access to the data as required. To investigate vegetation boundary extraction using relatively high resolution image data (2.7 ft. x 2.7 ft. pixels), four 255 x 255 pixel subscenes of representative land cover from one stored image were composited in DIAL's Image Memory Unit (512 x 512 pixels) for interactive analysis. The composite image was noise filtered (Figure 40) to reduce the 2 to 3 bits of noise included within the 8-bit quantization.

Vegetation generally can be classified adequately using a combination of the basic image and the derived texture image. Under these conditions, and with the resolution involved here, more than one signature* per vegetation class is often necessary to discriminate each class clearly from all other classes. Obtaining more than one signature per vegetation class increases the complexity of the analyst's problem and requires more interactive analysis time. However, some vegetation classes will always require more than one signature due to data variability within the class. Toward the goal of improving classification performance, the potential utility of a number of preprocessing steps was investigated. These steps included:

- Smoothing - via 2x2, 3x3, 4x4, 5x5 and 7x7 moving average operators

*A "signature" is two pairs of thresholds (or a rectangular partition) in 2-space. In general, it is a parallelepiped partition in N-space.

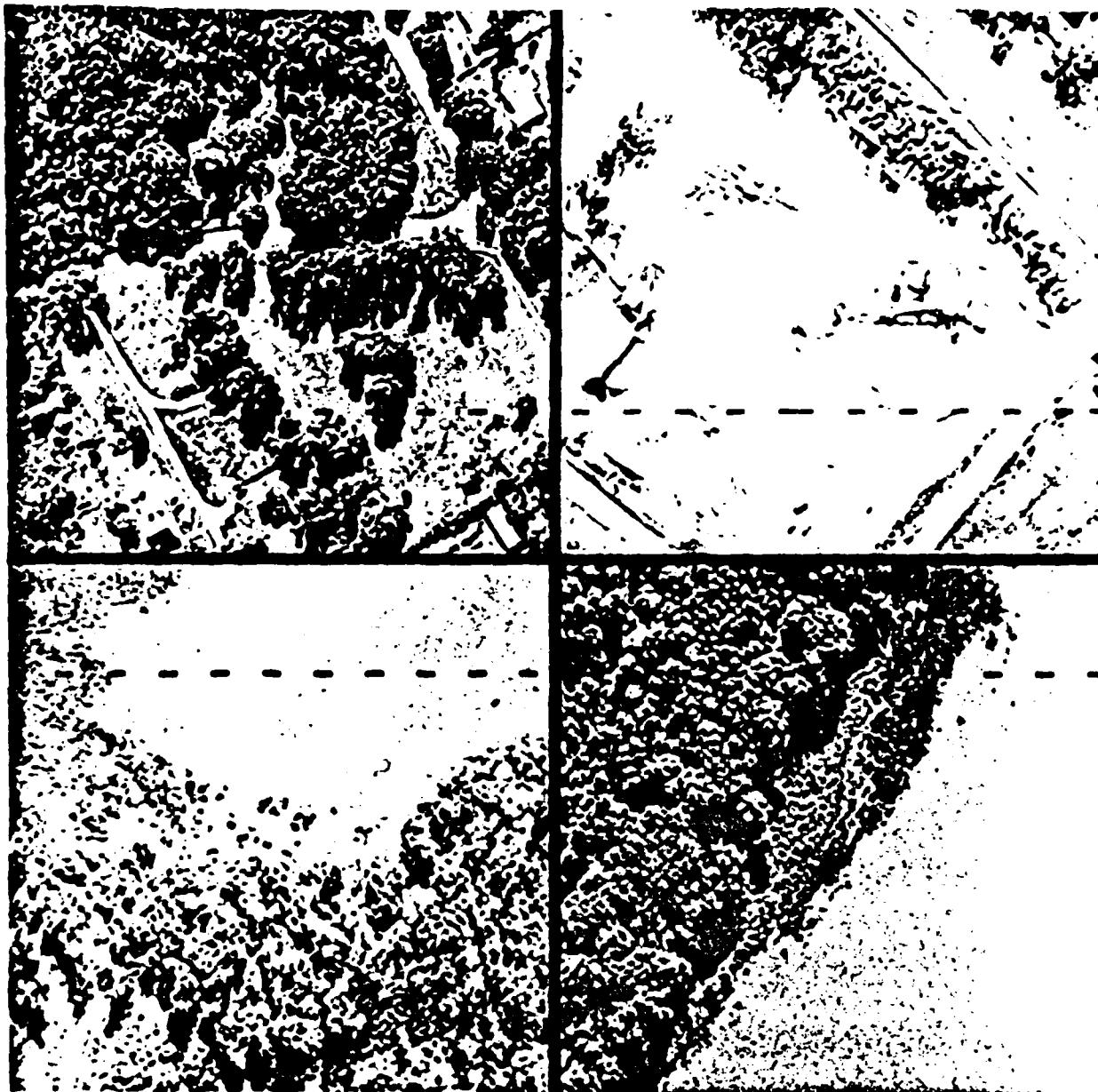


Figure 40. Fort Belvoir/Woodbridge Composite Image

- Resolution reduction - by creating a new image containing only every second, third, fourth, fifth or seventh pixel from local averages of the input image.
- Texture - 5-pixel cross and 9-pixel (3x3) rectangular templates
- Low-Pass Filtering

Nineteen different combinations of the above preprocessing steps were applied to the noise-filtered composite image (Figure 40). Some observations can be made concerning the preprocessing combinations studied and the classification results obtained using these combinations:

- Resolution Reduction: Local averaging and sampling are used to decrease apparent spatial resolution, to minimize the effects of vegetation fine structure, and to scale spatial variations relative to the texture template. For the composite image, resolution reduction greater than 3X appears to produce too severe a degradation in spatial resolution for purposes of generating 1:50,000 scale vegetation outlines. Acceptable texture outputs were obtained using 1X, 2X, and 3X reductions in resolution (pixel resolutions of approximately 2.7 ft., 5.4 ft. and 8.1 ft., respectively).
- Large Moving Averages: 5x5 pixel operators, or larger, are useful for smoothing out fine structure in image data so that results of classification are more homogeneous. But large moving averages create a border problem in the classification results. Vegetation boundaries, such as the forest-water boundary, were misclassified due to the averaging of adjacent light and dark areas. This produced a strip (proportional in width to the averaging operator used) of medium-gray tone areas along the forest-water boundary which falls within the signature of the grassland class.
- Smoothed Texture Image: Vegetation classes are more easily separated during classification when using a smoothed texture image. Some classes, formerly requiring multiple signatures, are separated with only one signature when smoothed texture is used. Large

moving averages, when used to achieve texture smoothing, create theme border problems while simultaneously easing the classification process. The opposite is true when small moving averages are used.

For a classification experiment, four preprocessing combinations, which were assessed as optimum, were selected as the inputs to a four-dimensional classification process.* The four input combinations are:

- a. 2x2 moving average on the 1X image
- b. 5x5 moving average on the 1X image
- c. 4x4 moving average on the 5-pixel cross texture output of the 2X reduced resolution image
- d. 2x2 moving average on the 5-pixel cross texture output of the 1X image

A four-dimensional parallelepiped classifier was used to derive eight vegetation classes from combinations of the four preprocessed images. The forest class (Figure 41) was derived mainly from combinations b and c, the highly smoothed input and texture images. With these two inputs the entire forest class could be defined with one signature. Misclassified areas include:

Large tree crowns. These are omitted falsely from the forest class but appear in the marsh brush class because of similarities in gray tone and texture.

Tree shadows which extend into other vegetation classes. These are falsely included in the forest class. Exclusion of the shadows from the forest class, however, would create omissions in the forested area in the lower right quadrant where tree shadows fall on other trees.

The resulting vegetation classes show the need for an acceptable theme processor which can remove small misclassified areas and create more

*Normally, two-dimensional classification is used (e.g., a digital image and its smoothed texture version are the inputs). In this experiment, four inputs are used in several combinations.

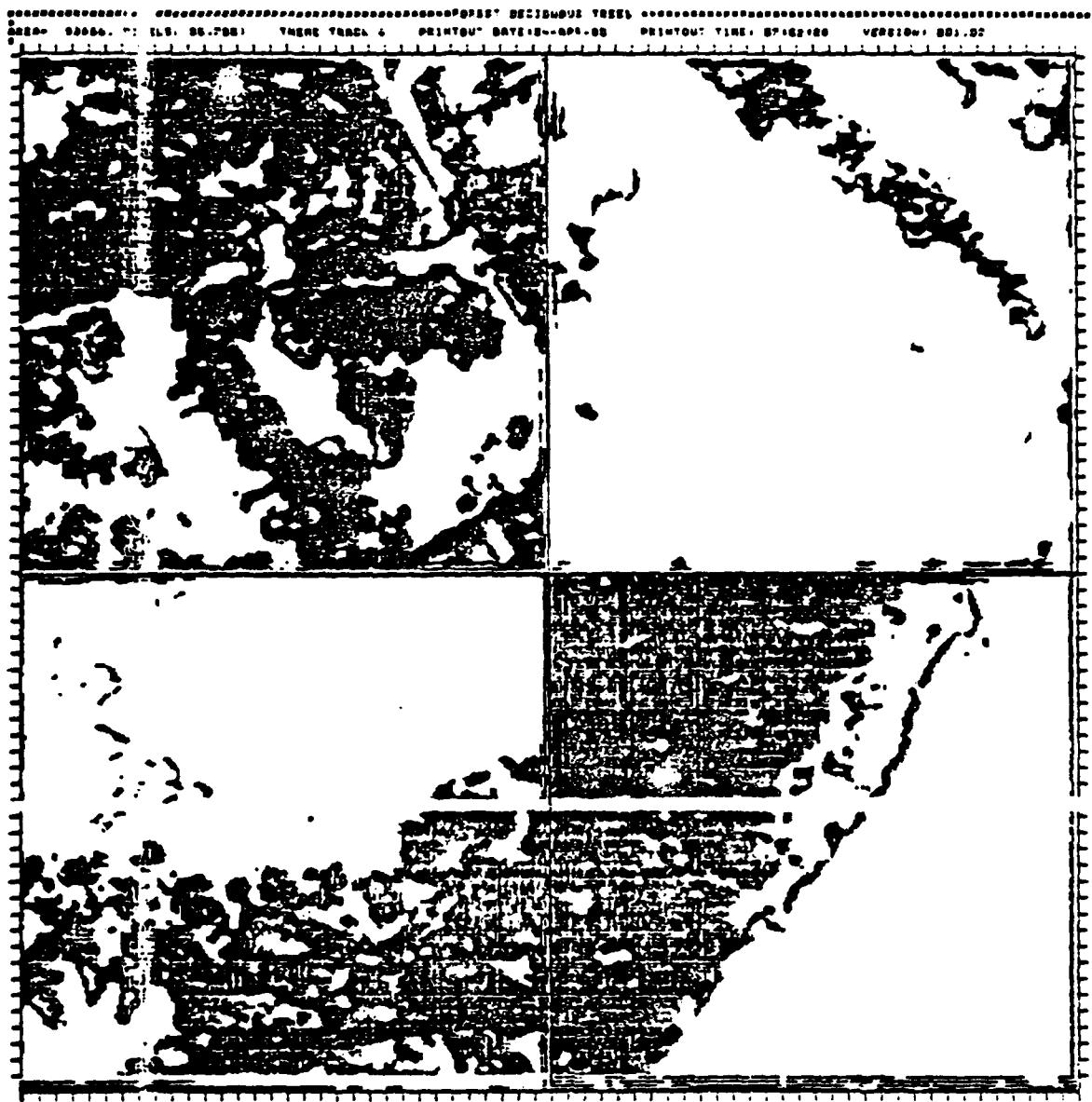


Figure 41. Forest Theme for the Fort Belvoir/Woodbridge Composite Image.

homogeneous vegetation classes. Of course, it must be recognized that this experiment began with the use of relatively high resolution image data (2.7 ft. x 2.7 ft. pixels). Some increase in classification difficulty is expected in this situation. This level of input image resolution probably is not necessary (and often is undesirable) for the production of most vegetation boundary factor overlays.

A second approach to vegetation classification for the Ft. Belvoir/Woodbridge image data involves reducing the resolution of the image before further analysis. The principal requirement for resolution reduction for vegetation classification purposes is that the resulting image must have information from which the texture operator can extract information needed to separate forest, grass, and water. As determined previously, resolution reduction greater than 3X appears to degrade this image too severely for purposes of extracting textural information. By using a 3X reduction, less data manipulation is required (fewer pixels cover the same scene area), while simultaneously textural information remains present as necessary for vegetation classification. The resulting image after a 3X reduction contains 537 x 537 pixels, with the linear dimensions of each pixel being approximately 8.1 feet.

512 x 512 pixels of the reduced resolution image were transferred to the Image Memory Unit for further analysis. The 5-pixel-cross min-max texture operator was applied to the image. The resulting texture image contains the information necessary for discrimination of forest, grass and water. A very-low-pass filter (7x7 moving average) was then applied to the texture image to increase separability of those classes. The original image was also smoothed (7x7 moving average) to remove noise and to attempt an increase in homogeneity of the derived classes. Two approaches were used to derive the vegetation classes via 2-D classification:

- a. Reduced resolution image vs. its smoothed texture image
- b. Smoothed reduced resolution image vs. the smoothed texture image, as shown in Figure 42 bottom left and right, respectively.
(The unsmoothed versions of these images are at upper left and right).

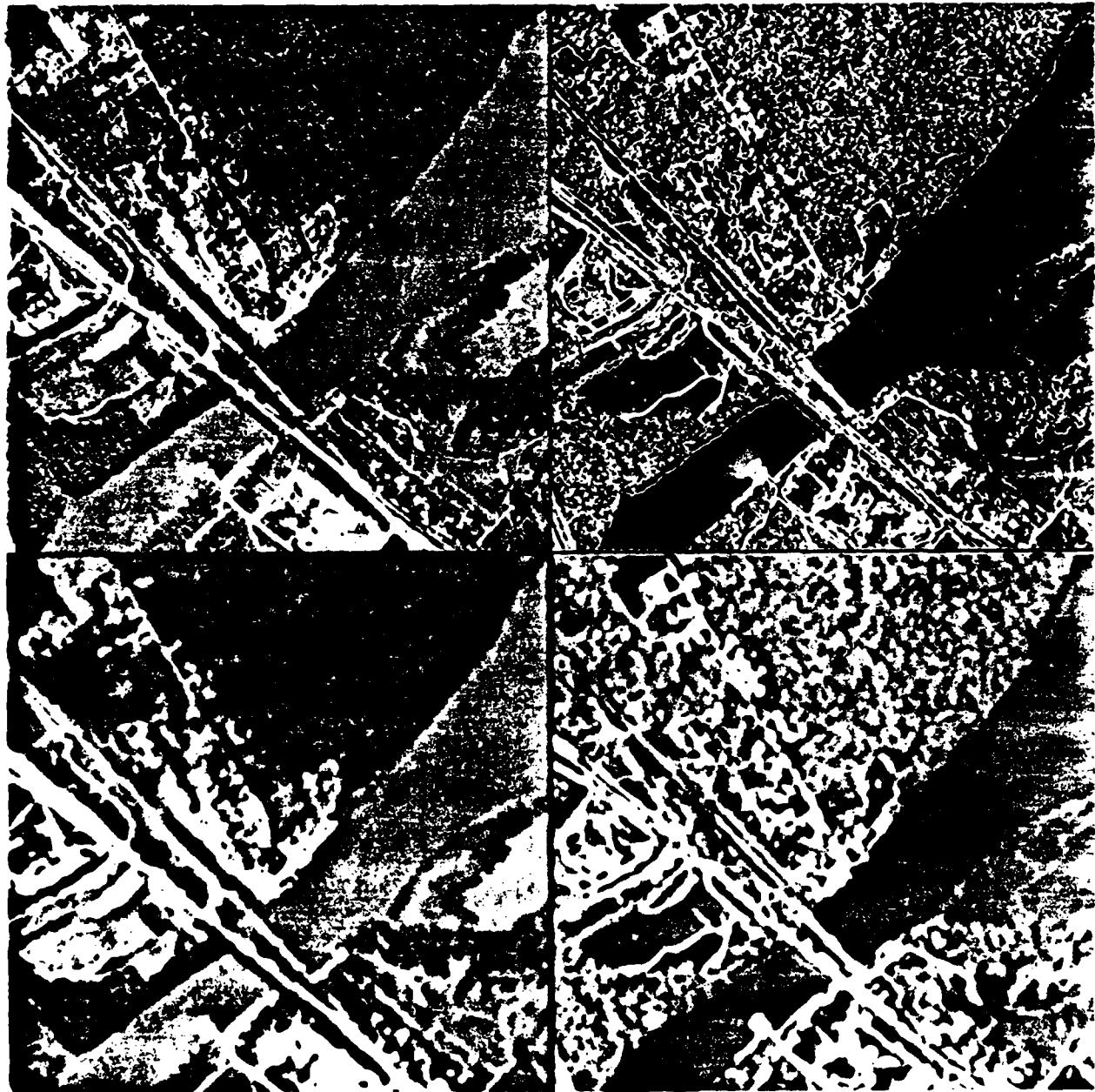


Figure 42. Fort Belvoir/Woodbridge Reduced Resolution Image (Top Left), Texture Image (Top Right), and Smoothed Versions (Bottom)

The first approach yielded a good classification but with noisy output themes (which can be improved via a theme-smoothing processor). For the second approach the result was a good but less noisy classification. However, the need for an acceptable theme processor still is apparent. Further, in this approach, theme border problems arise which ultimately must be resolved. For this particular application test, the classification themes produced under the conditions of the second approach (b) were carried through a smoothing operation via the Golay theme processor. The result is shown in Figure 43.

Reviewing the results of the analysis of this scene, the preferred approach is to use the reduced resolution, unsmoothed image with its smoothed texture image to derive the vegetation classes. Then, an appropriate theme-smoothing processor should be applied.

2. Pennsylvania Scene (Initial Analysis)

A 512 x 512 pixel subscene, containing appropriate land cover with data in the green and thermal infrared bands, was extracted from the 5000-foot altitude flight line image. The 5000-foot altitude data were chosen based on the assumption that the resolution (8 x 11 foot pixels) approximates that which is required to produce an optimum texture output (an output which easily discriminates forest, grass and water). The green and thermal band subscene images are shown at lower left and lower right, respectively in Figure 44.

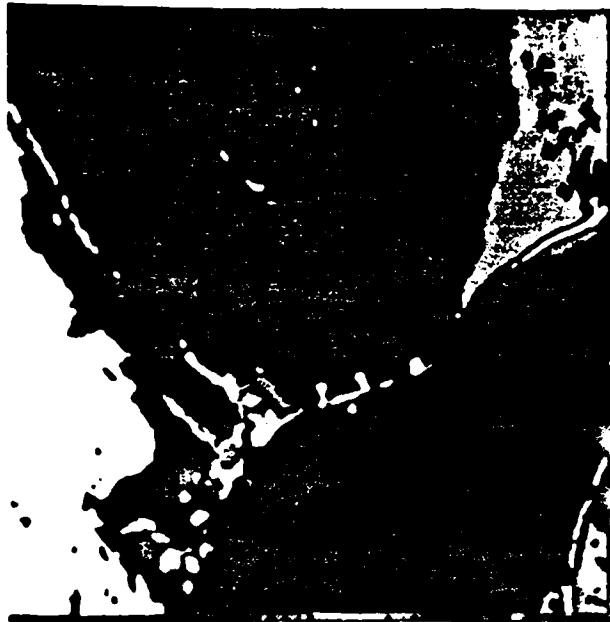
Several variations of smoothing the green and the green texture images were examined for discrimination of vegetation classes. As in the Fort Belvoir/Woodbridge scene, the preprocessing chosen was the 7x7 moving average applied to both the green band data and its derived texture image (5-pixel cross min-max). This results in better discrimination of the vegetation classes and minimum fine structure in the class themes.

Two-dimensional classification using the smoothed green image and the smoothed green texture image was employed to produce a classification of three land cover categories: forest, grass and bare. In the 2-D scatter diagram (Figure 45) two distinct clusters are apparent. The larger cluster



White	- Bare
Light Gray	- Marsh
Medium Gray	- Forest
Dark Gray	- Grassland
Black	- Water

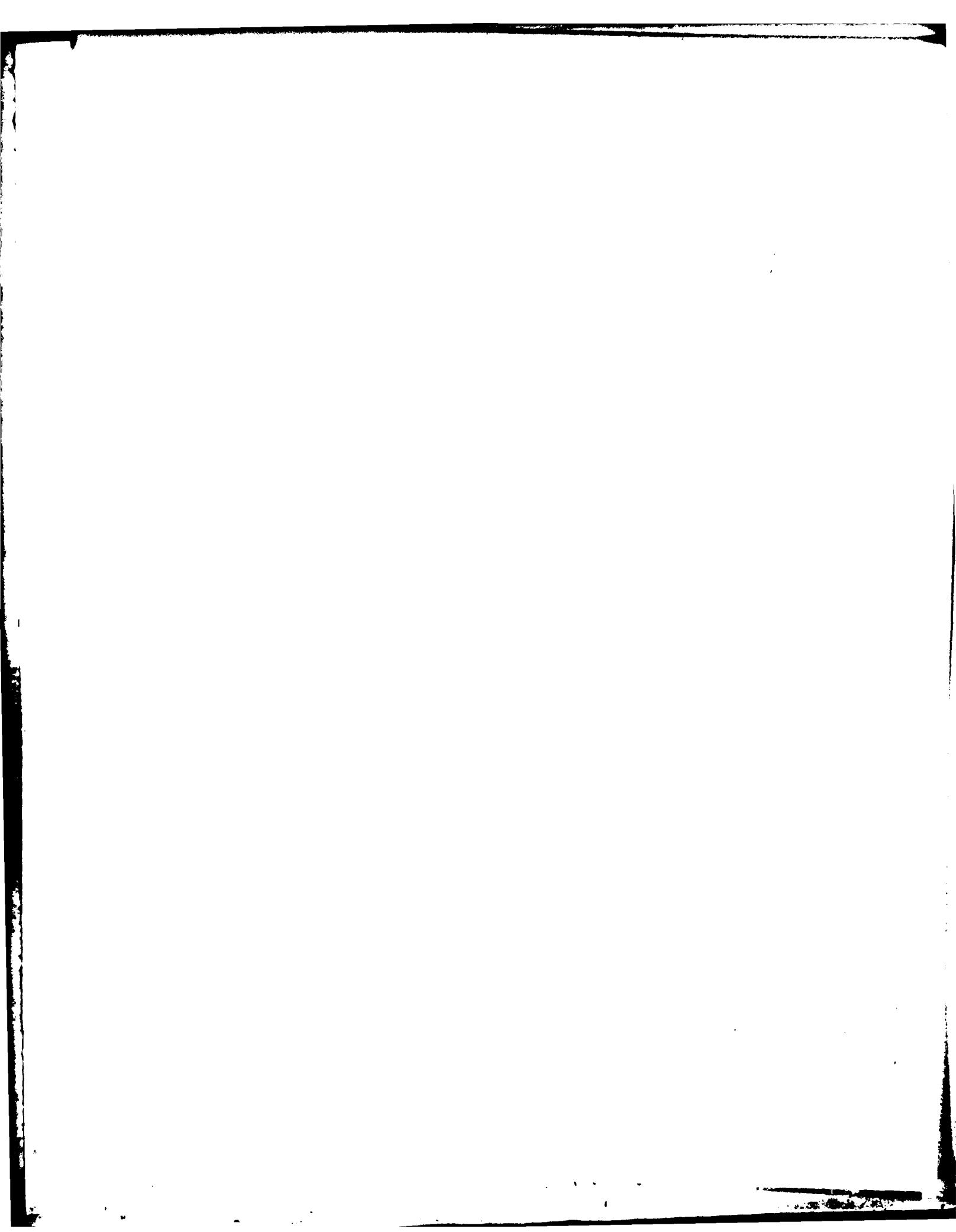
Figure 43. Vegetation/Land Cover Classification for Fort Belvoir/Woodbridge Image

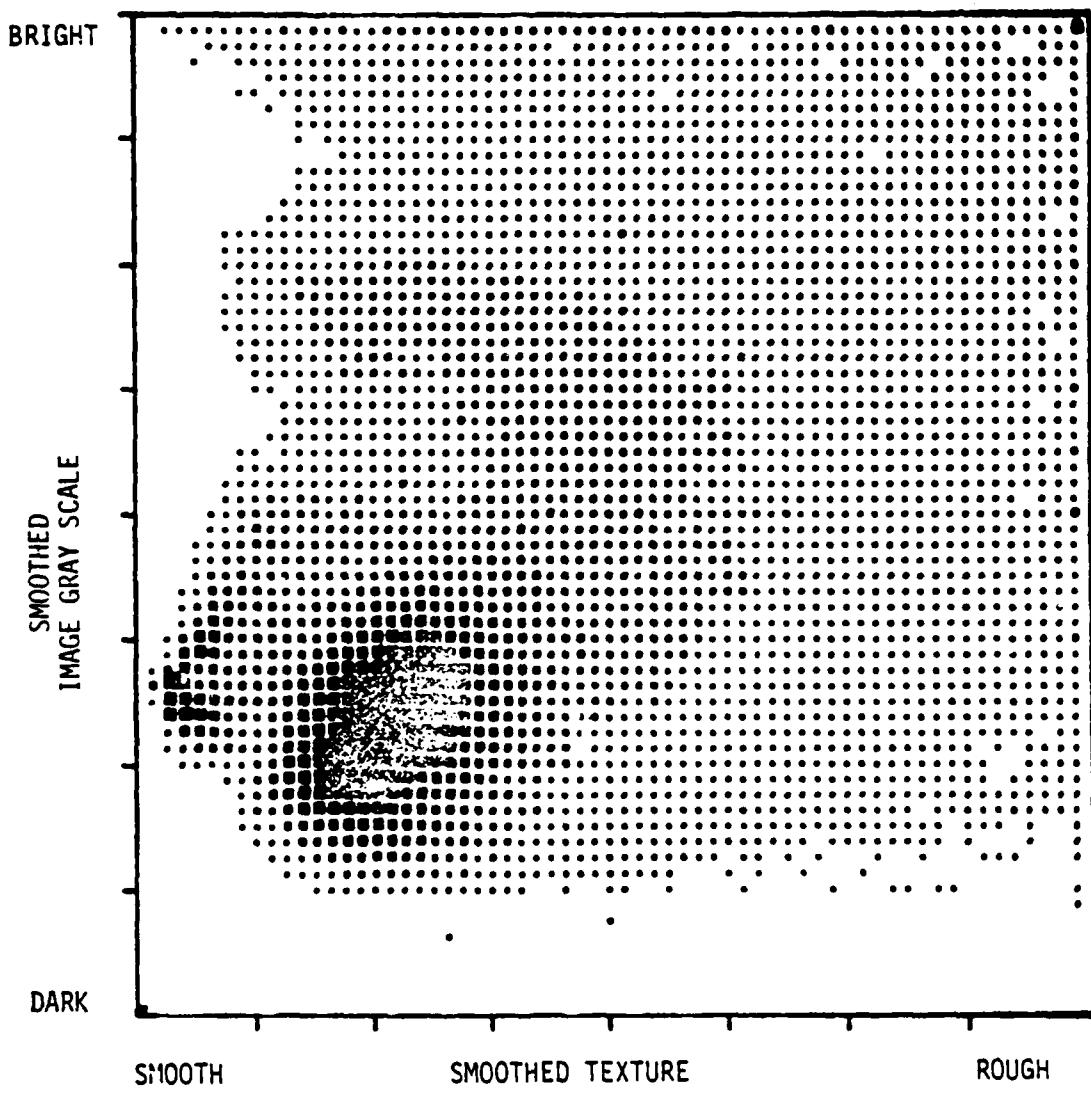


BAFE
BRASS
FOREST
WATER



Figure 44. Pennsylvania Green and Thermal Images (Bottom Left and Right) and Vegetation/Land Cover Classification (Top)





Two-dimensional projection of gray scale vs. smoothed texture for the 5,000 ft. altitude Pennsylvania data.

Figure 45

corresponds to forest, and the smaller cluster represents grass with a small amount of water. At this resolution, water and grass are very similar in texture, with water having slightly less texture than grass. Thus, it appears that water and grass, which generally have similar reflectance in panchromatic imagery, can often be discriminated by use of textural information. However, because of specular reflection from the water in this particular green image, the decision was made to derive the water class from the smoothed thermal and the smoothed thermal texture images. Figure 46 shows the smoothed green and thermal images (upper left and right), and the smoothed texture versions of these images (lower left and right).

Results of the four-category classification are shown as four themes in different shades of gray in the upper image of Figure 44. These results are considered to be fairly good, with one exception. In the grassland area at the upper right there is an incorrect inclusion of small areas of the forest theme. This apparently resulted from high textural characteristics in portions of the grassland. An analyst, working interactively with machine aids, should be able to resolve this conflict, but no attempt was made to do so in this test.

3. Florida Scene

This scene was used for further testing of the vegetation extraction techniques developed for the Fort Belvoir/Woodbridge and the Pennsylvania scenes.

Two-dimensional classification, using the smoothed green input image and the smoothed green texture image (7x7 moving average in both cases), was employed to classify forest, citrus plantation (upper left in the scene), grassland and bare areas. Classifying water without false inclusions was again difficult using only the green images. Therefore, the water theme was produced from the thermal infrared image and the smoothed thermal texture image. See Figure 47 for the green and thermal input images (upper left and right), and the derived texture versions of these images (lower left and right). Figure 48 shows these same images after smoothing.

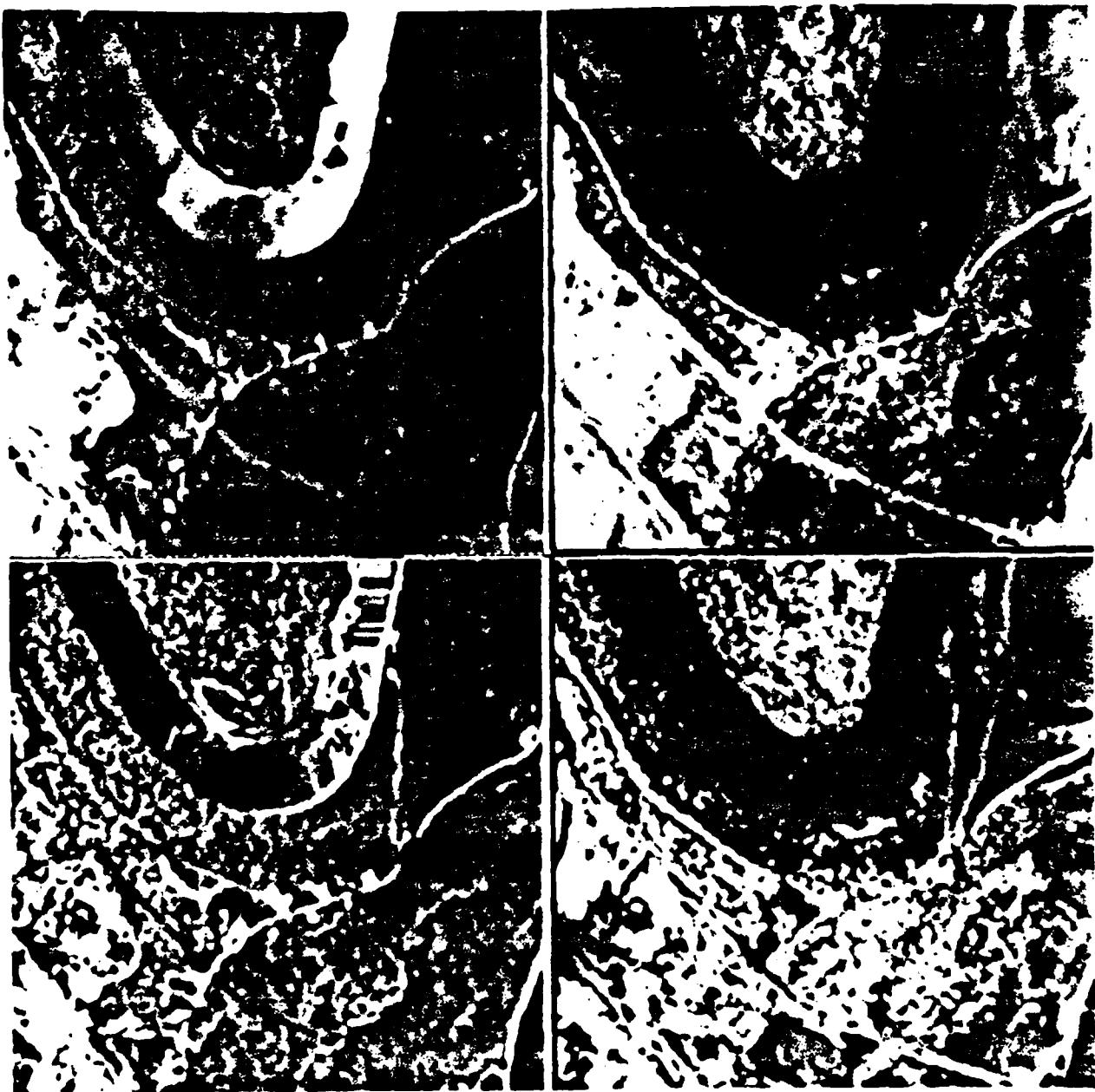


Figure 46. Pennsylvania Smoothed Images: Green (Top Left), Thermal (Top Right), and Texture Versions (Bottom)

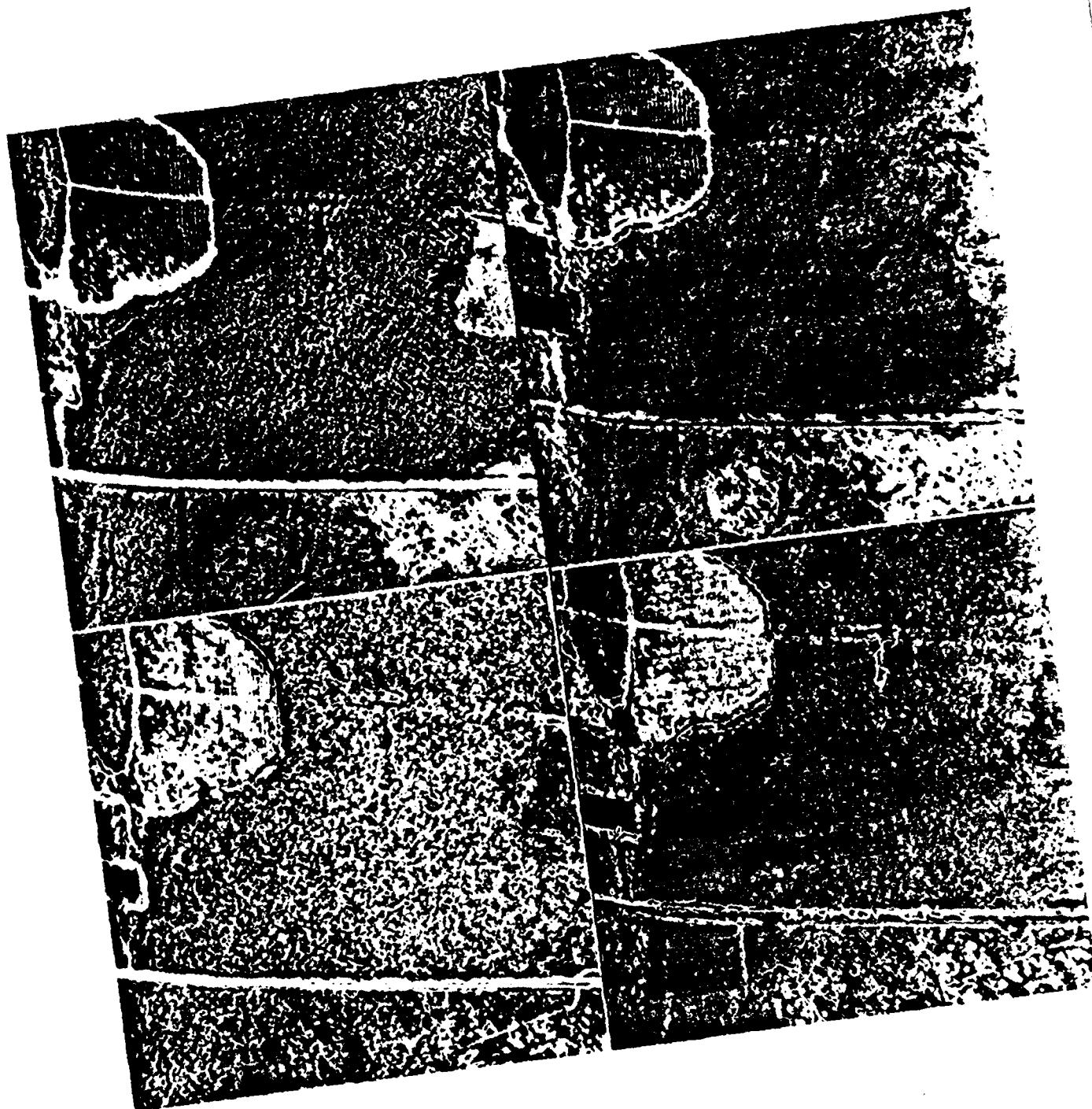


Figure 47. Florida Images: Green (Top Left),
Thermal (Top Right), and Texture Versions
(Bottom)

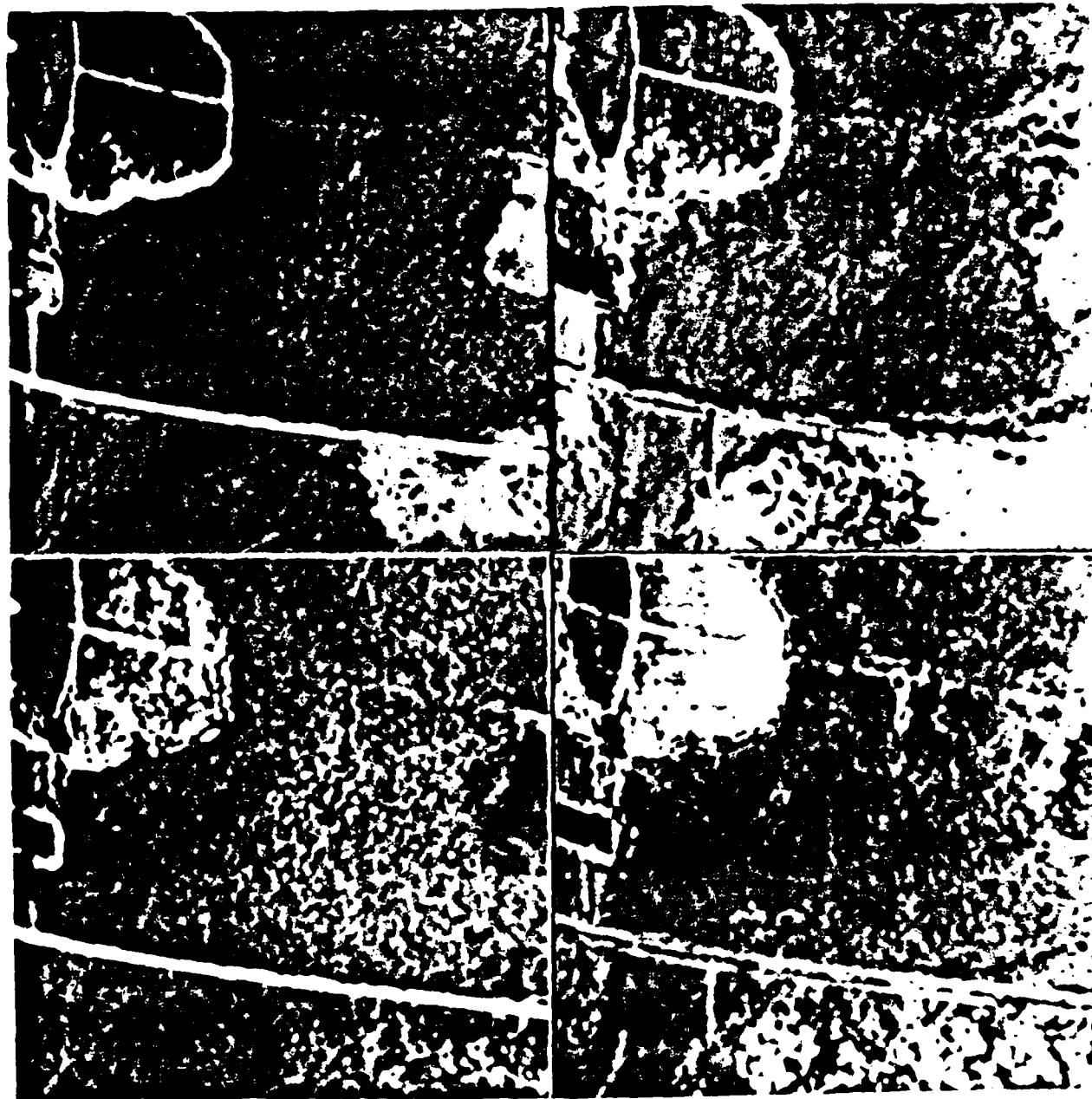


Figure 48. Florida Smoothed Images: Green (Top Left), Thermal (Top Right), and Texture Versions (Bottom)

Results of the total scene classification are shown in Figure 49. Five themes are presented in shades of gray. Although the shading for the water theme (black) and the forest theme (dark gray) are similar, these features were separately and cleanly discriminated. Again, classification results are considered to be fairly good. There appear to be no serious errors of omission or commission, although perhaps there is a little too much "bare" classification in the grassland area at the lower right in the scene.

D. Comprehensive Application of the Boundary Extraction Procedure

1. Introduction

The Pennsylvania scene data were chosen for this analysis for several reasons, most important of which are (a) the availability of multiple altitude data (i.e., multiple resolution data), and (b) the large area covered by the data. Reason (b) means that a very realistic test is possible, particularly since a good variety of terrain conditions are involved. In contrast to the previous analyses, all steps in the boundary extraction process were implemented here - starting with the input image data and continuing through the production of a vegetation/land cover boundary map similar in form to a factor overlay.

There were also some changes in the extraction procedure. First, noise filtering of the raw data was eliminated since it did not appear to affect classification results. Second, no smoothing of the input data was used. This avoided the theme border problem, although it did lead to more "noisy" vegetation themes. Accordingly, the themes were subjected to a different smoothing operation than that used in previous analyses. While reasonably acceptable results were achieved, the theme smoothing technique is inefficient and probably too simplistic, and warrants a much more thorough investigation.

Finally, it is to be noted that texture processing was not used with the high (20,000-foot) altitude data. Texture images have been found to be a key input to the vegetation classification operation in all analyses. But, in the case of the 20,000-foot altitude data, the data resolution was simply too coarse to enable the texture operator to extract information useful for distinguishing between forest and grassland/agriculture.



Figure 49. Vegetation/Land Cover Classification for Florida Image

2. Detailed Procedure

Figure 50 presents a flow chart showing the steps in the analysis. The green channel data (0.50-0.55 μm) and the thermal infrared channel data (8-14 μm) were extracted from the multispectral scanner output tapes for the 5000, 10,000 and 20,000-foot altitude flight lines and used for the subsequent analysis. Digital recordings of the unprocessed (input) image data for the three altitudes, each with green and thermal infrared information, are shown in Figure 53, 54 and 58. The images are each presented at the same scale, approximately 1:50,000.

All input image data, green and thermal for the three altitudes, were subjected to the 5-pixel cross min-max texture extractor. The derived texture images then were smoothed by a 7 x 7 moving average to increase the separability of the vegetation classes. Figures 53, 55 and 59 show the resulting smoothed green and thermal texture images for the 5,000 ft., 10,000 ft. and 20,000 ft. altitude data at 1:50,000 scale.

Classification of the vegetation is the next operation, and it draws upon the unsmoothed green and thermal images plus the smoothed texture versions of these images. However, because a fairly large scene area is involved (7-mile strip having 2000 scan lines for the 10,000-foot altitude data), an intermediate step is necessary. A composite subscene is prepared in order to enable extraction of vegetation/land cover signatures which are applicable to the total scene. The basic problem here is that terrain feature signatures often vary from one location to a second, distant location in a large scene. Variations in the atmosphere, aspect angle and the terrain features themselves are some of the causes. But, all of the scan lines in a large scene cannot be analyzed interactively at the same time, even though this would be desirable for signature extraction. In the GE DIAL system the limit is 512 lines of 512 pixels each for interactive analysis (although much larger areas may be processed in batch mode).

There are solutions available, however, for interactive extraction of vegetation signatures in a large scene. One possibility is to examine every fourth line of the 2000 total scan lines. Instead, the option chosen here was to select four strips of data from different locations in the flight-

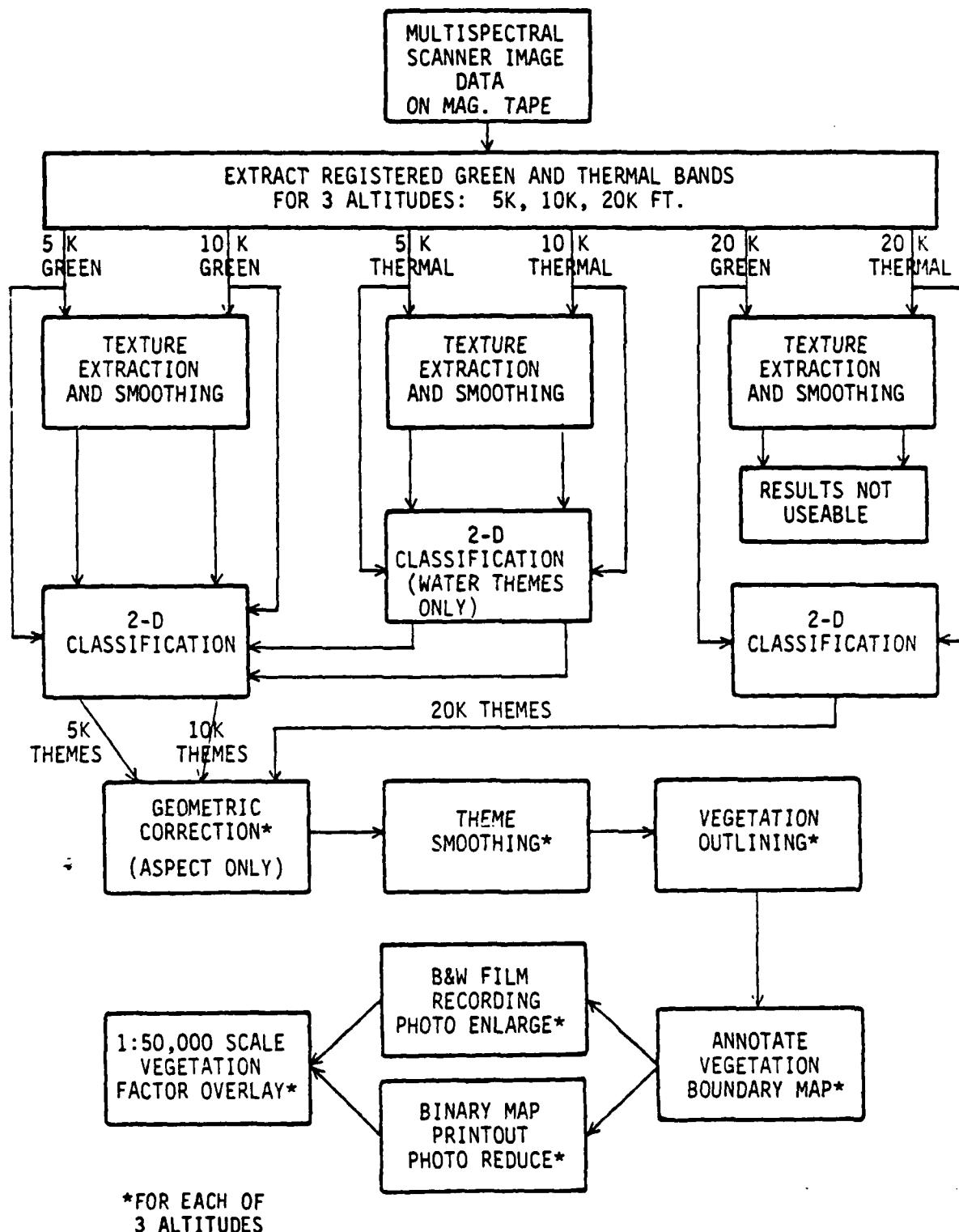


Figure 50. Procedure for Pennsylvania Vegetation Boundary Extraction.

line so as to include a good representation of the vegetation/land cover. This is illustrated in Figure 51. The four strips each contain 128 consecutive data lines of 512 pixels each. These are composited into a 512 x 512 pixel array for signature extraction. No composite subscene was created for the 20,000-foot altitude data, however, since one 512 x 512 pixel subscene covers the entire area of interest.

Vegetation signature extraction (and thereby vegetation classification) is performed for the composite subscene via an analyst interactively establishing rectangular partitions in 2-space consisting of green image data vs. smoothed green texture data. However, due to the specular reflection from the water in this particular green image, it became necessary to use the thermal and the smoothed thermal texture data to derive the water class.

Because of spectral and textural variations within some vegetation categories, several 2-D signatures in combination are often used to define one vegetation class. Six such signatures excluding water, were obtained from the 2-D classification (green vs. smoothed green texture) for the 10,000 and 5,000-ft. altitude data. These signatures, plus the water signature, were then applied to the entire flightline and the resulting themes combined into five vegetation/land cover classes: water, needleleaf forest, broadleaf forest, grassland/agriculture, and bare.

Due to the scan rate, sampling rate and speed of the aircraft in acquiring these data, distances between pixels and distances between scan lines are not equal. To achieve a 1:1 aspect ratio for all image recordings in this analysis, all images (input or processed) were resampled (aspect corrected) prior to recording. The vegetation themes, aspect corrected, for the 5,000-ft. altitude data are shown at 1:50,000 scale in Figure 53, and for the 10,000-ft. altitude data in Figure 56.

Preliminary interactive classification of the 20,000-ft. altitude data, using the green and smoothed green texture images, yielded unacceptable results. Due to the low data resolution at this altitude, the texture operator was unable to extract useful textural information for distinguishing between forest and grassland/agriculture. The problem involved

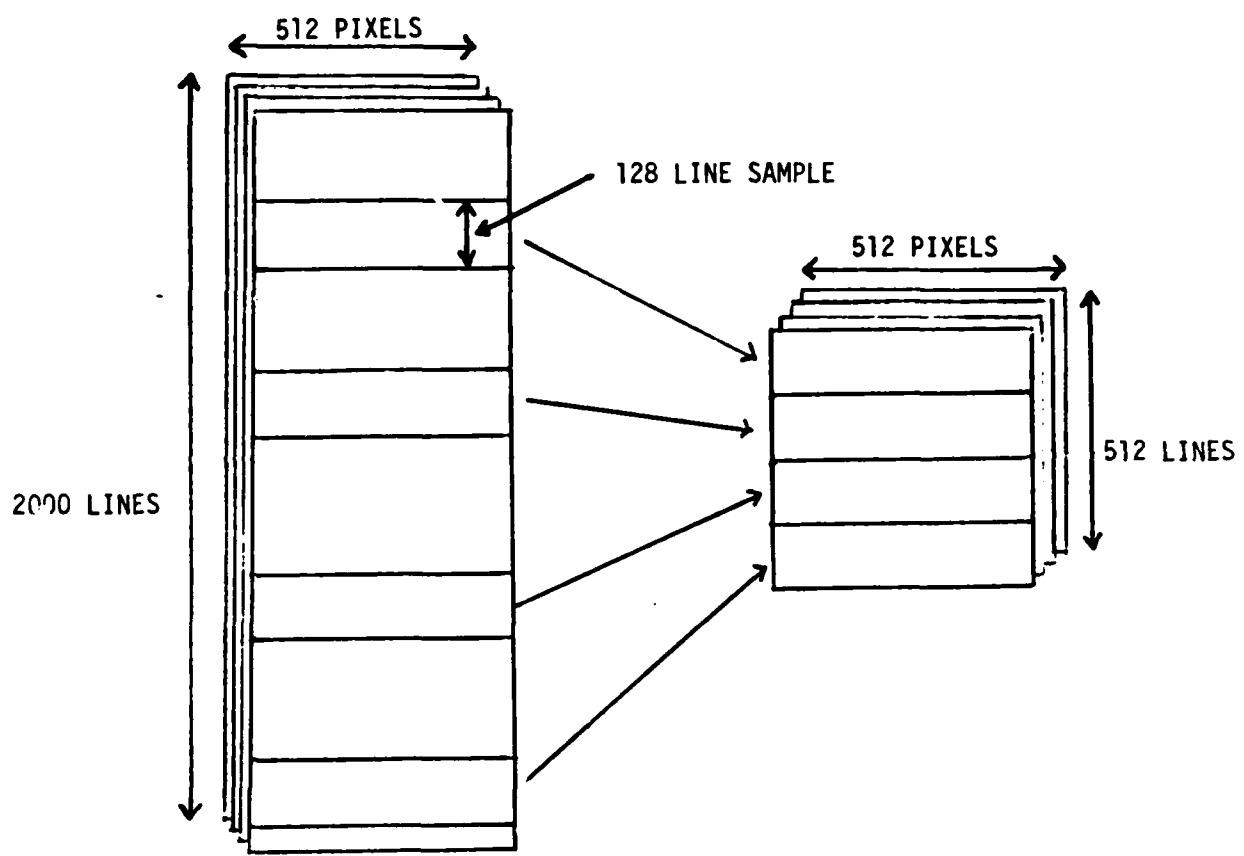


Figure 51. Composite Subscene Generation for Classification.

here becomes apparent upon examination of the three 2-D scatter diagrams of the green image data vs. the smoothed green texture data for the 5,000, 10,000 and 20,000-ft. altitude flights. See Figure 52. As resolution becomes poorer, the two clusters (the larger being forest and the smaller being grass), which are easily distinguishable in the 5,000-ft. altitude data, are much closer in the 10,000-ft. altitude data, and appear to merge in the 20,000-ft. altitude data. Because the clusters are not separable, it was necessary to obtain all the vegetation classes for the 20,000-ft. altitude data from joint use of the green and thermal image. Using classification in a 2-space comprised of green vs. thermal image data, seven signatures were extracted which were combined to produce five vegetation themes for the 20,000-ft. altitude data: water, needleleaf forest, broadleaf forest, grassland/agriculture, and bare. Digital recordings of themes are shown aspect corrected at 1:50,000 scale in Figure 60.

The vegetation/land cover themes from the classifications for the three altitudes were subjected to a simplistic smoothing operation to remove much of the fine structure prior to theme outlining. The results of this smoothing are shown at 1:50,000 scale for the 5,000-ft., 10,000-ft., and 20,000-ft. altitude data in Figure 53, 56 and 60. Comparison of the smoothed themes and the raw themes shows that some narrow features (roads and water courses) are removed by the smoothing operation. To resolve this problem, the narrow features, which should be included in the vegetation maps, can be interactively extracted from the raw themes and added to the smoothed themes. Figure 61 shows, for the 10,000-ft. altitude data, the smoothed themes (right) and the smoothed themes with the narrow features included (left).

Next, the smoothed vegetation themes for the 5,000-ft. and 10,000 ft. altitude data were edged via the Golay Processor. The resulting vegetation outlines are shown at 1:50,000 scale in Figures 53 and 57, respectively. However, the 20,000-ft. altitude data were not carried through this step.

A portion of the vegetation outlines for the 10,000-ft. altitude data was interactively annotated to illustrate what might be the appearance of a final vegetation boundary factor overlay. See Figure 62.

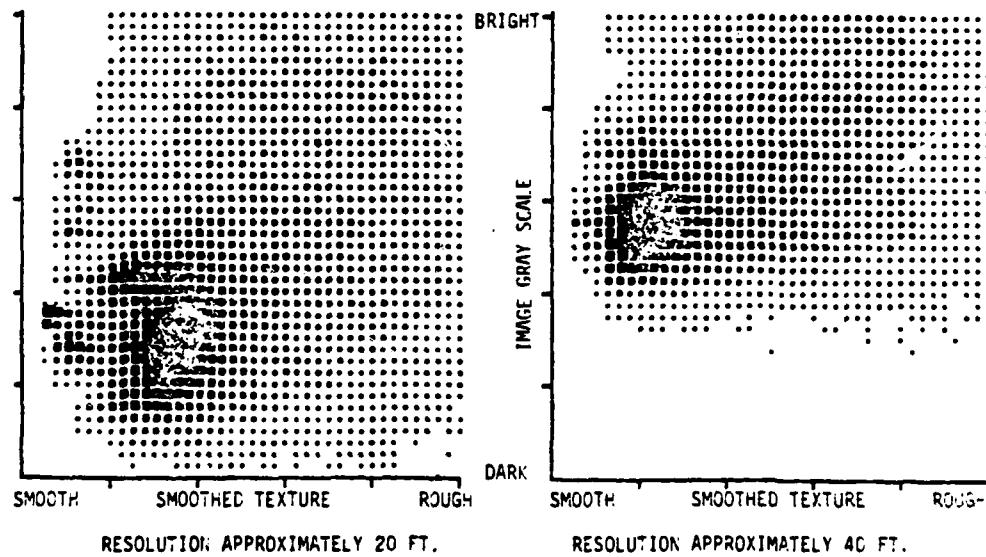
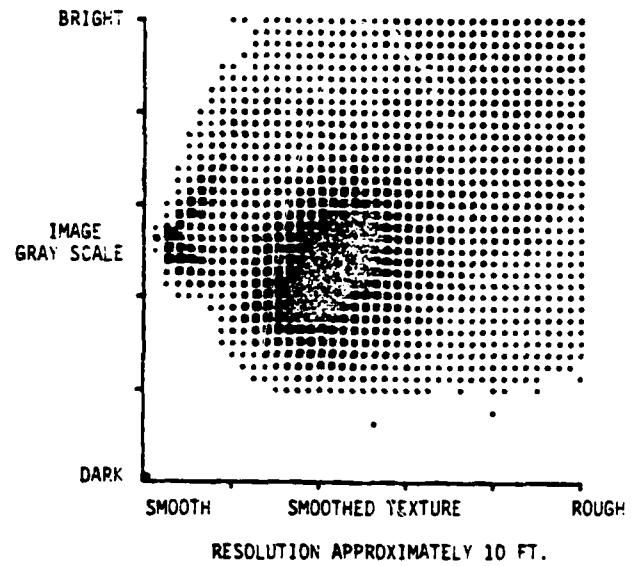


Figure 52. Image Gray Scale vs. Smoothed Texture for Three Values of Spatial Resolution.

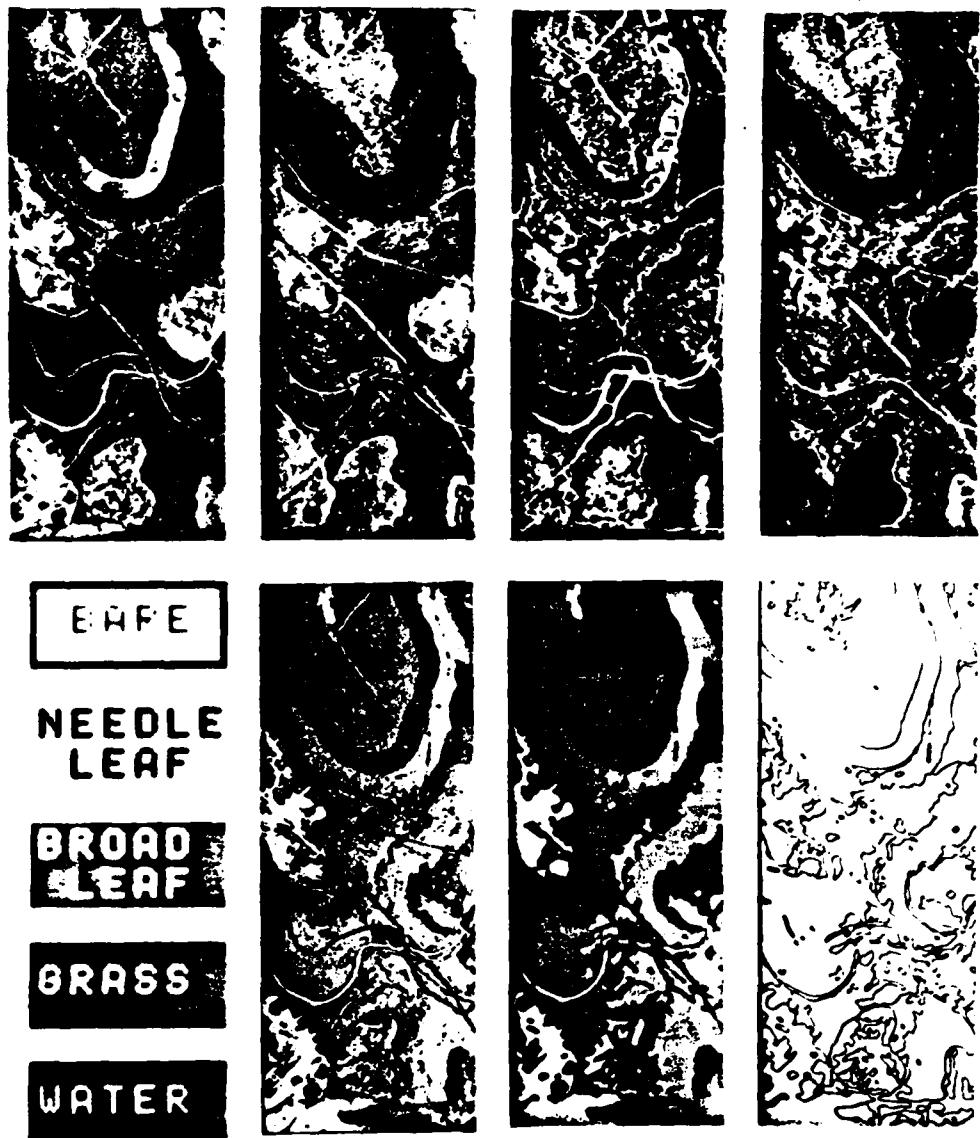


Figure 53. Pennsylvania 5000-foot Altitude Images:
 Green, Thermal, and Smoothed Texture
 Versions (Top); Raw, Smoothed and
 Outlined Vegetation Themes (Bottom)

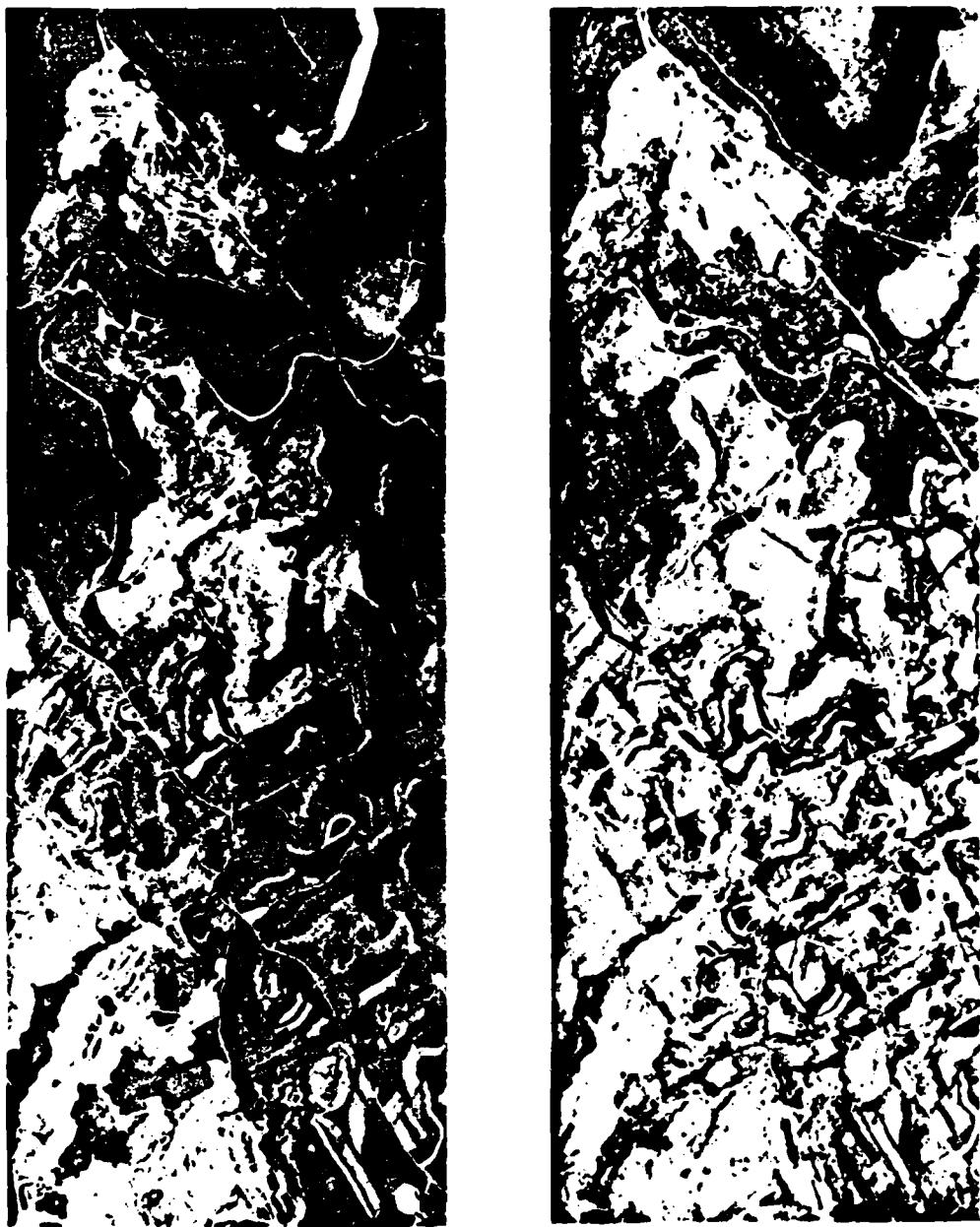


Figure 54. Pennsylvania 10,000-Foot Altitude Images:
Green (Left), Thermal (Right)

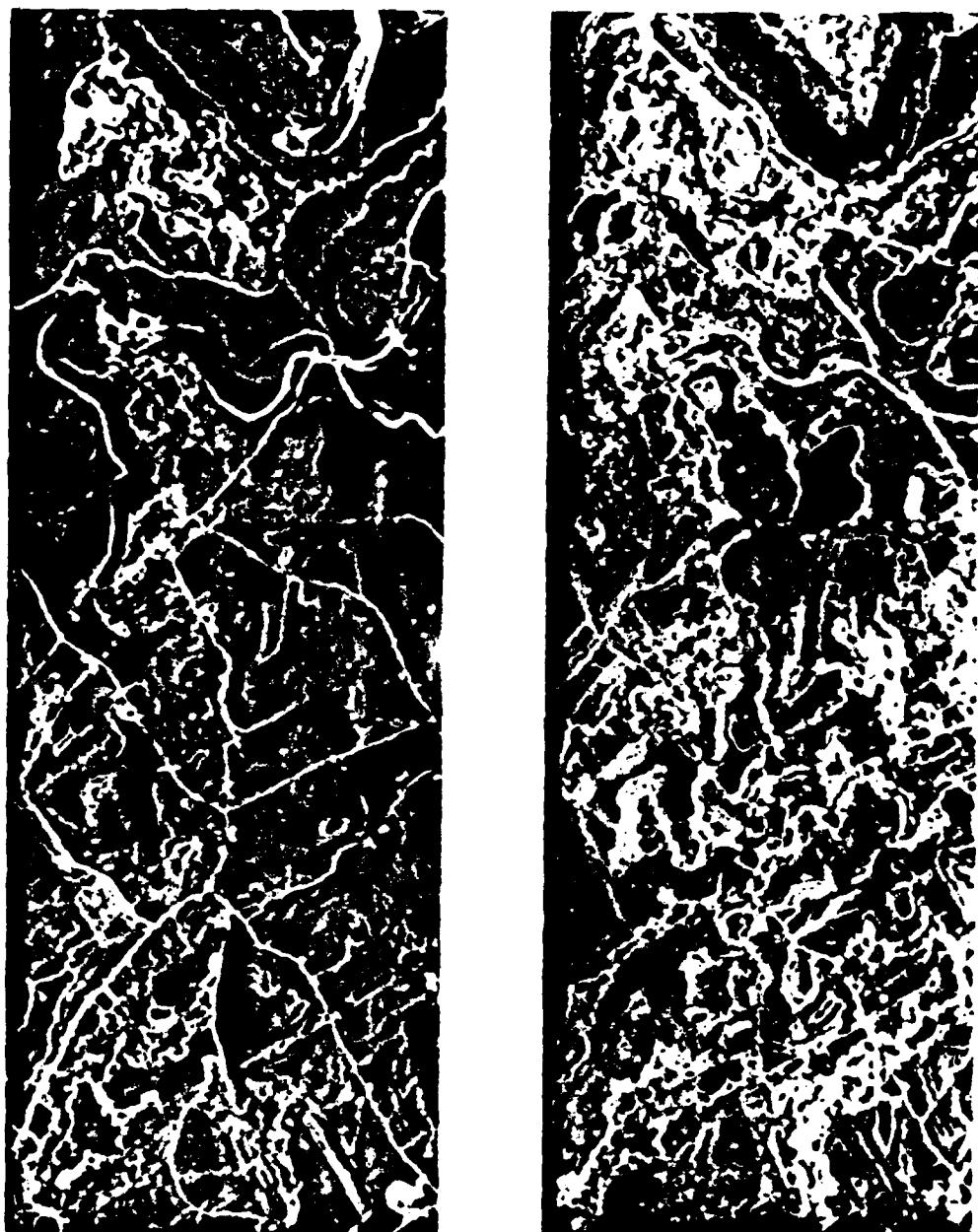


Figure 55. Pennsylvania 10,000-Foot Altitude Smoothed Texture Images:
Green (Left), Thermal (Right)

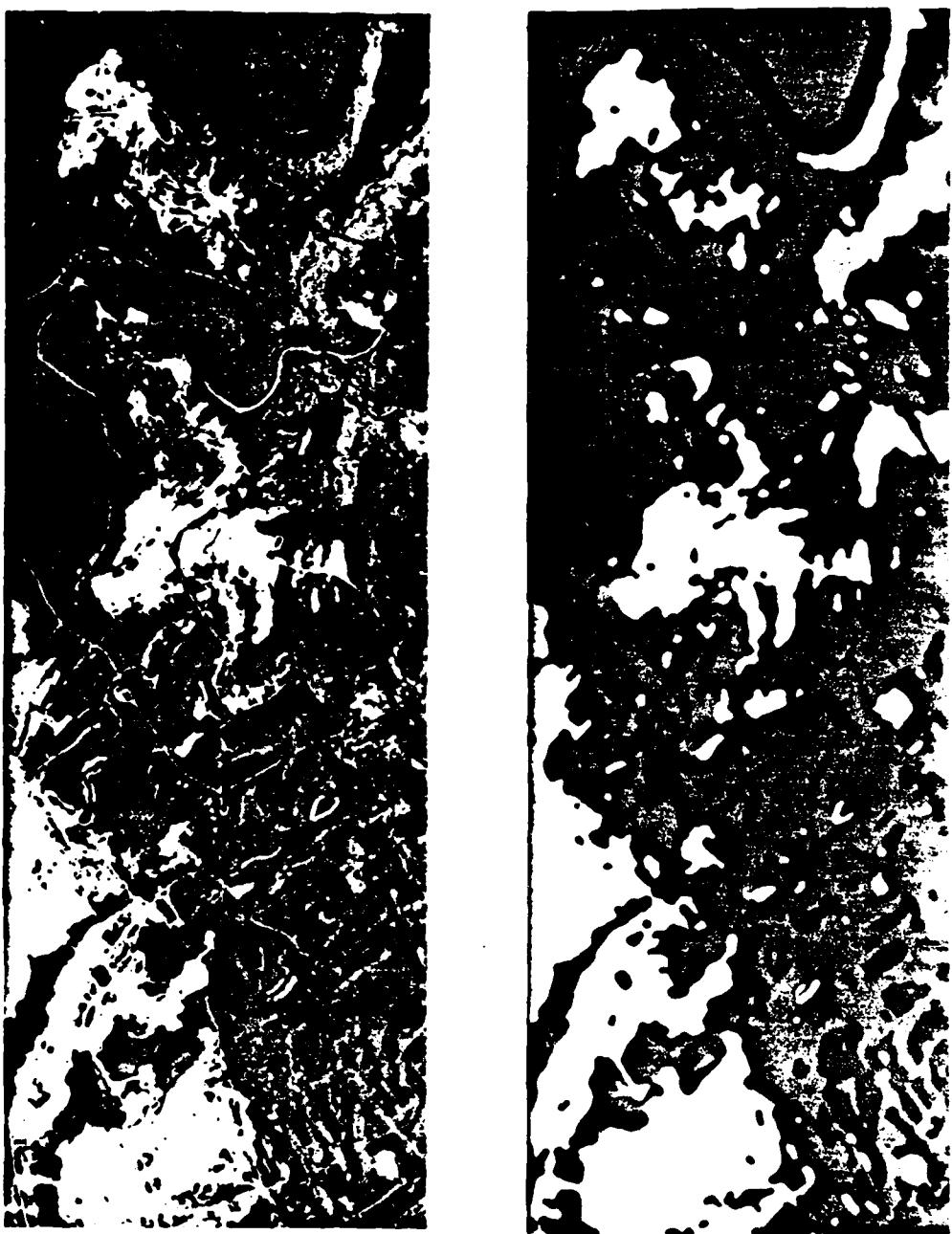


Figure 56. Pennsylvania 10,000-Foot Altitude Vegetation Themes:
Raw (Left), Smoothed (Right)



Figure 57. Pennsylvania 10,000-Foot Altitude Vegetation Theme Outlines

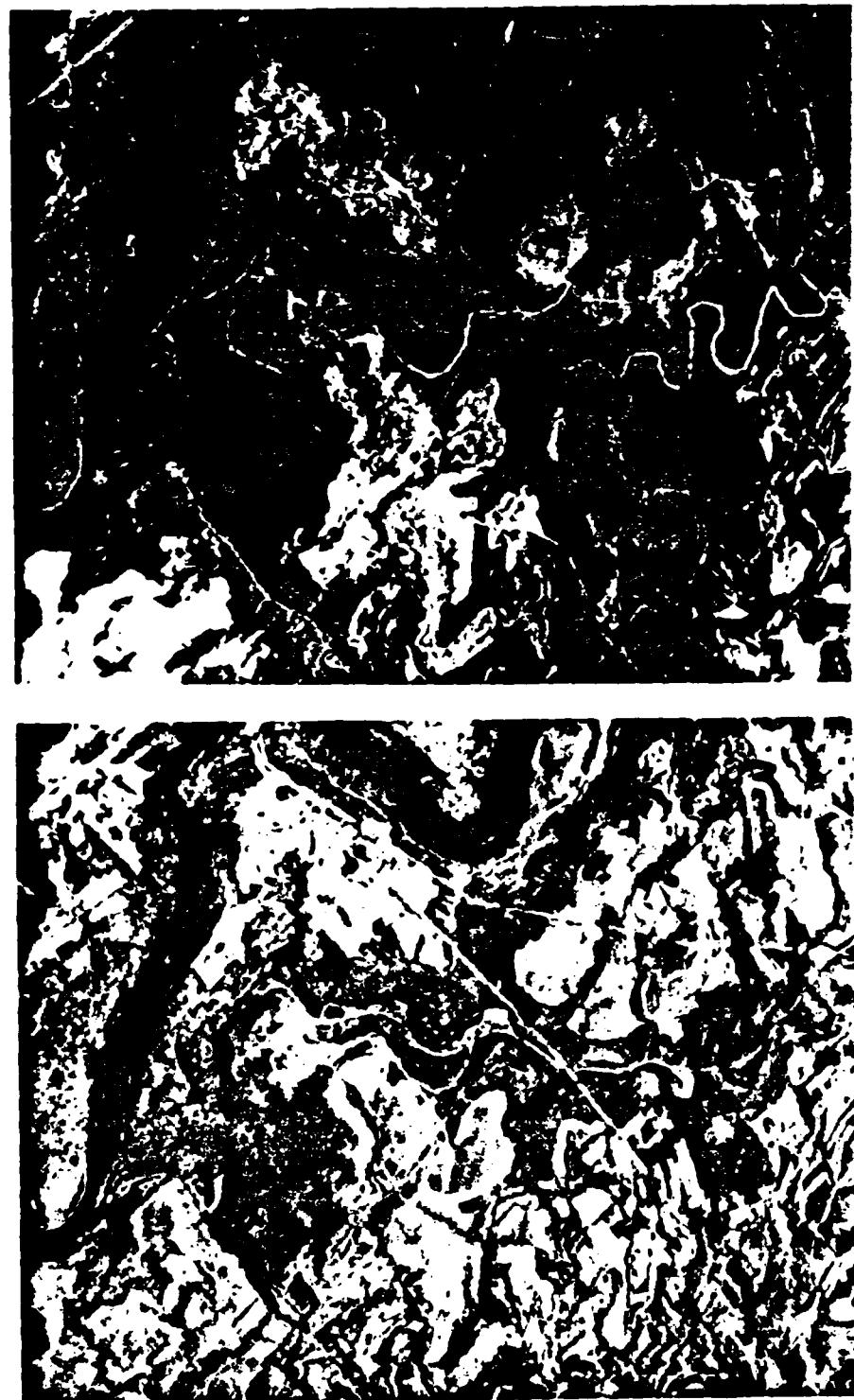


Figure 58. Pennsylvania 20,000-Foot Altitude Images:
Green (Top), Thermal (Bottom)

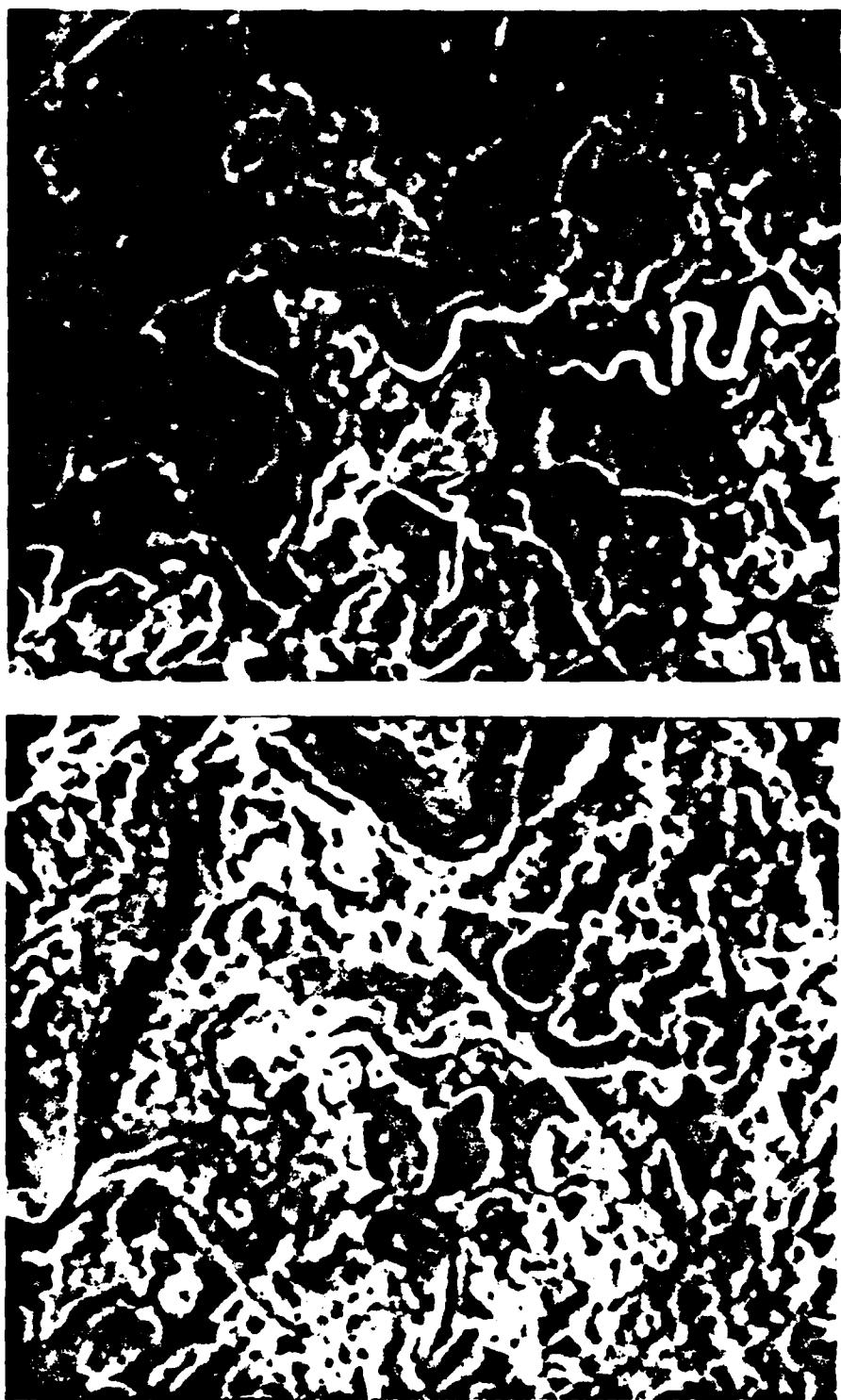


Figure 59. Pennsylvania 20,000-Foot Altitude Smoothed Texture Images:
Green (Top), Thermal (Bottom)

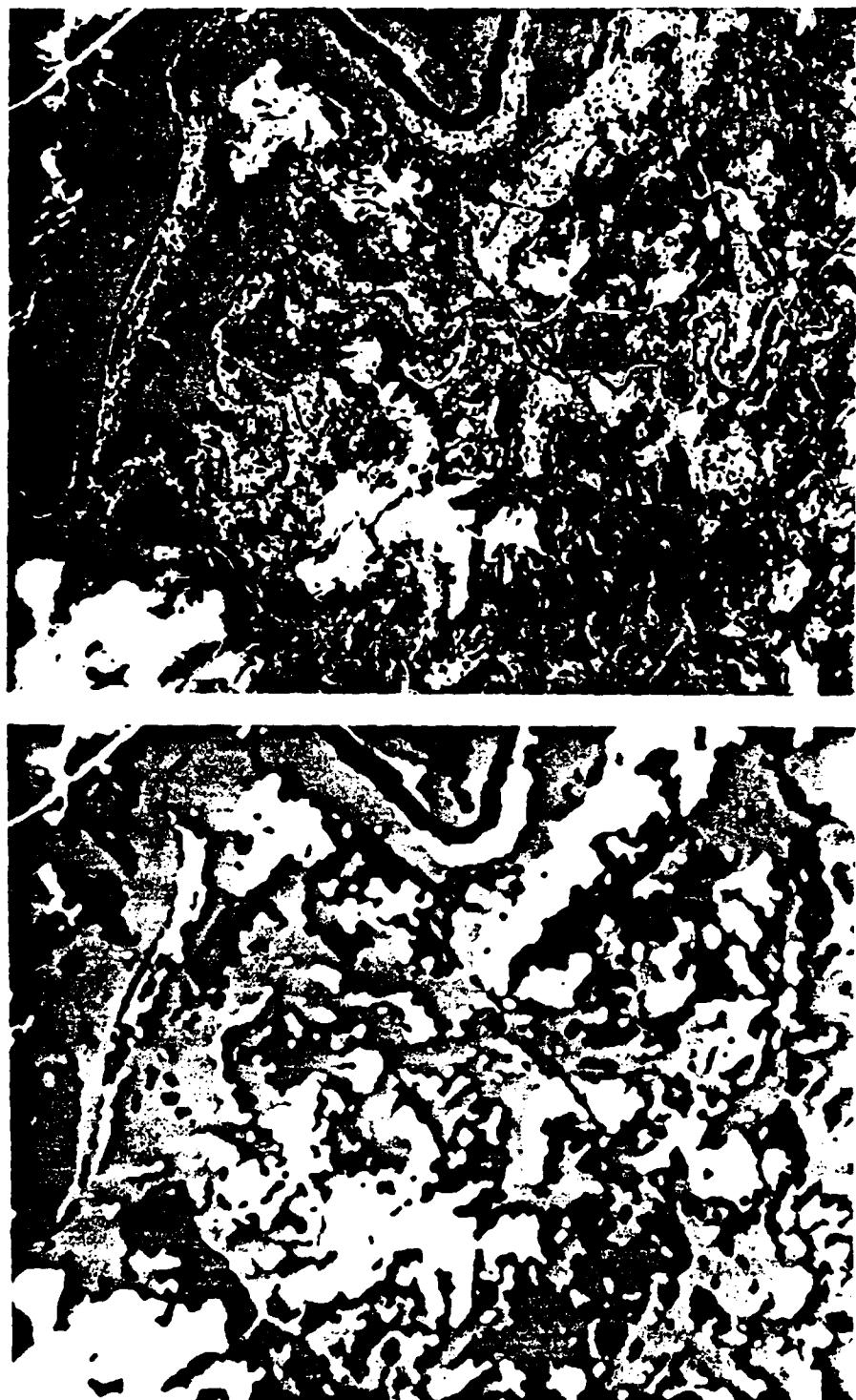


Figure 60. Pennsylvania 20,000-Foot Altitude Vegetation Themes:
Raw (Top), Smoothed (Bottom)

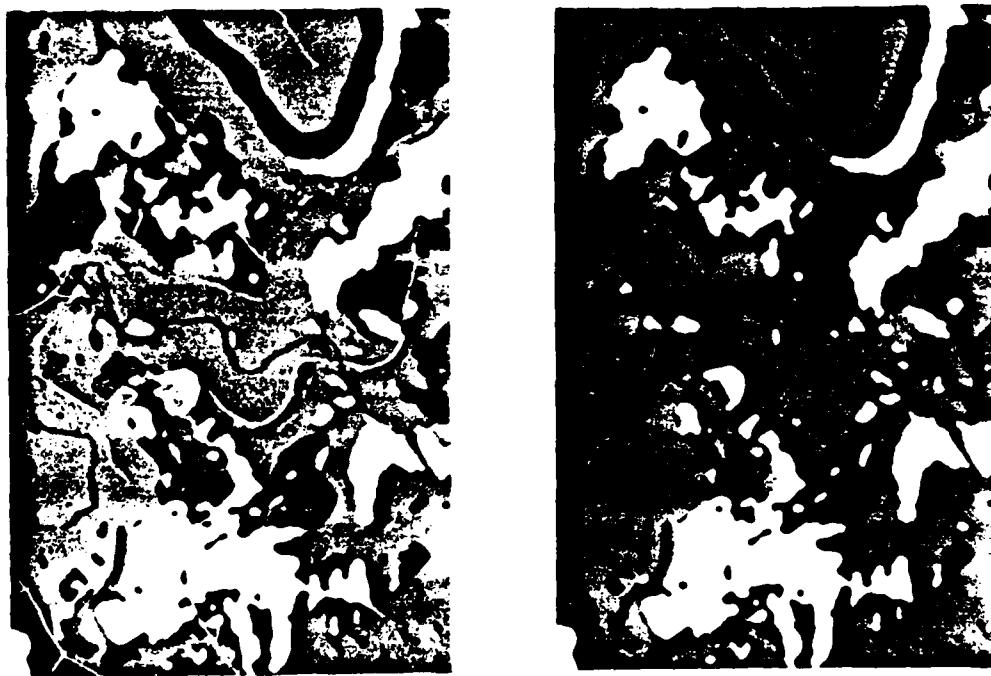


Figure 61. Pennsylvania 10,000-Foot Altitude Themes
with Addition of Narrow Themes (Left).
Before Addition (Right)

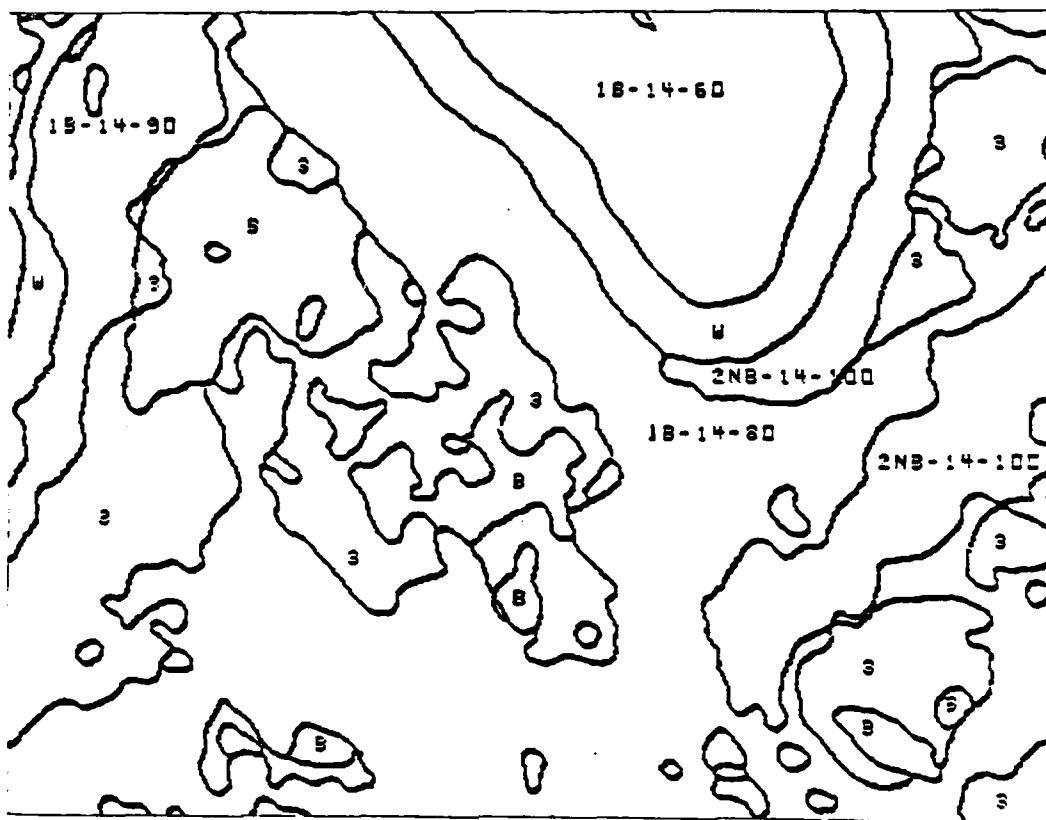


Figure 62. Annotation of Portion of Pennsylvania 10,000-Foot Altitude Vegetation Outline Themes.

3. Spectral Band Considerations

Two questions are addressed in this section: (a) Is the use of the multispectral scanner green band data an acceptable simulation of digitized panchromatic photography? (b) Is green (or panchromatic) imagery adequate by itself to enable good vegetation/land cover boundary extraction, or must it be supplemented?

To examine the first question, a subscene of the 10,000-foot altitude scanner data was analyzed in accordance with the procedures described previously, but with three different scanner spectral band combinations used to simulate the panchromatic photography. These combinations are assembled from four scanner bands: Band 4, 0.50-0.55 μ m; Band 5, 0.55-0.60 μ m; Band 6, 0.60-0.65 μ m, and Band 7, 0.65-0.70 μ m. The three combinations used are:

- A. Band 4
- B. Bands 4 + 6 (equal weighting)
- C. Bands 4 + 5 + 6 + 7 (equal weighting)

Spectral sensitivity of aerial black-and-white films is fairly uniform between 0.40 and 0.70 μ m. If a minus blue filter is used to minimize atmospheric backscatter effects, then overall sensitivity is concentrated mainly between 0.50 and 0.70 μ m. Therefore, combinations A, B and C are reasonable choices.

The 5-pixel cross min-max texture operator was applied to the digital images produced from each band combination. Figure 63 shows the input images (left) and the smoothed texture images (right) at 1:50,000 scale for the three band combinations. The green band alone (A) appears to exhibit some atmospheric effects of dust and/or haze which are visible in the left portion of the image. This is not as apparent in the images for combinations B and C. Overall, there are few significant differences among the texture images for the three band combinations. However, the texture image from combination C appears to contain more easily separable forest and grassland classes and less easily separable grassland and water classes than from the green band alone.

2-D classification involving input image vs. smoothed texture image for each band combination, was performed. Nine signatures were extracted and

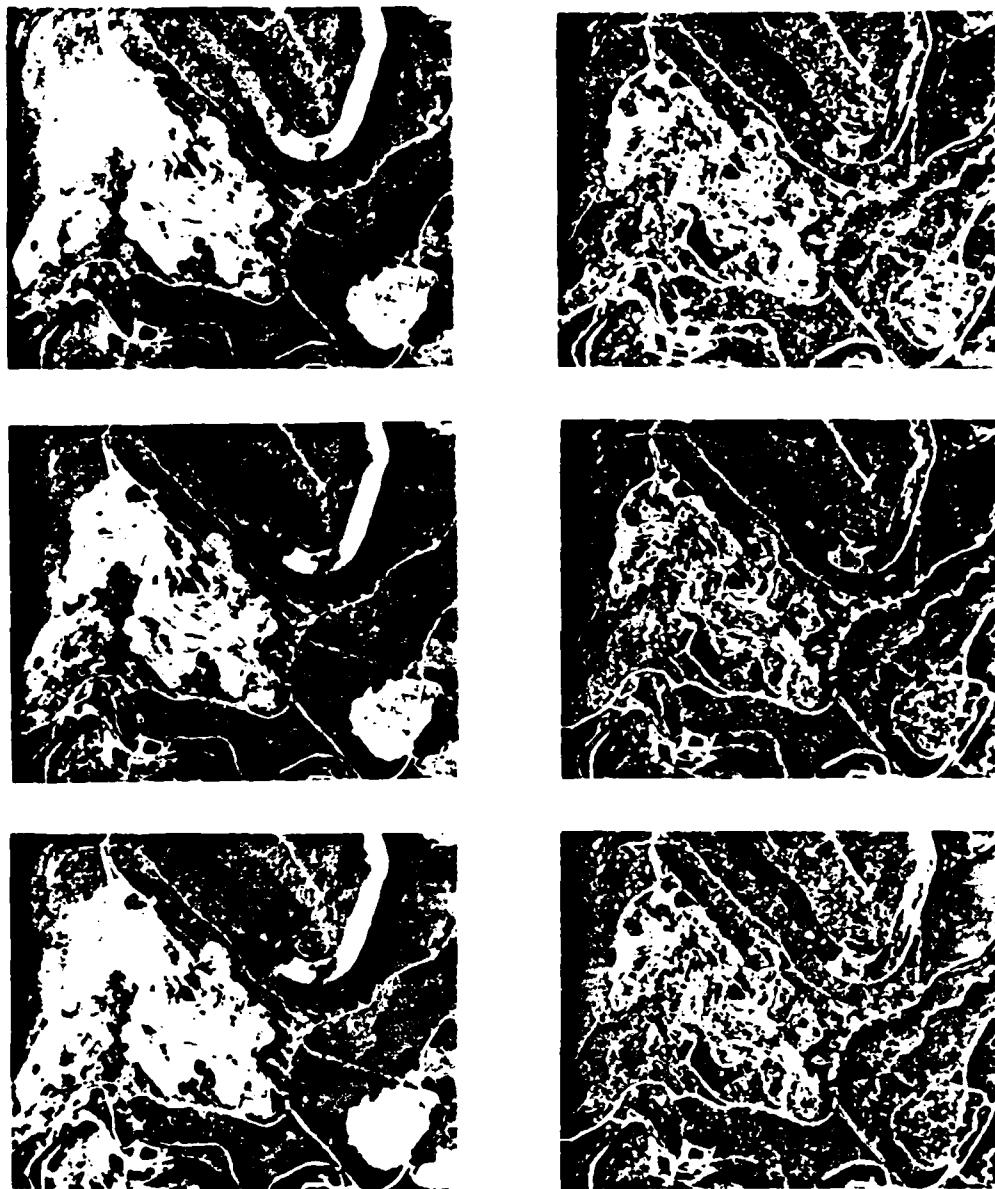


Figure 63. Three Spectral Band Combinations:
Original Images (Left), and Texture
Versions (Right). Bands A, B, C
Top to Bottom

combined into five vegetation classes. The resulting themes are shown at 1:50,000 scale in Figure 64 (left), and the smoothed themes are shown at the right in the same figure.

Comparing the classification results for the three band combinations, a few comments can be made:

- Bare areas and needle leaf forest areas are mapped basically the same for all three combinations, with minor variations due to operator judgment as to the break point between classes.
- The grassland and forest boundaries differ for all three combinations, but trade-offs occur in each case. The forest is mapped better in combination B than in the others, but the area of grassland on the left is false. Combination C yields results very similar to those for the green band alone (A).
- For combination C the water class is somewhat harder to map without false inclusions.

It is concluded that use of the green band alone has been a reasonable but not ideal simulation of panchromatic photography. Classification using panchromatic imagery (similar to combinations B or C) could be more difficult in a few instances than using green band data only. But there are other instances in which the classification is likely to be slightly easier.

To answer the second question, the classification results using green band image data only (Figure 64, top) may be compared with results obtained previously using thermal data to derive the water class and green data to derive the other classes (Figure 56). Ignoring the area of specular reflection in the water, the results of water classification using green data only were relatively poor. The river at the top and right of the image was almost completely identified, but the creek in the lower portion of the image was missed totally. Also, there are some false inclusions in the water class of a few areas of grassland throughout the image. Water

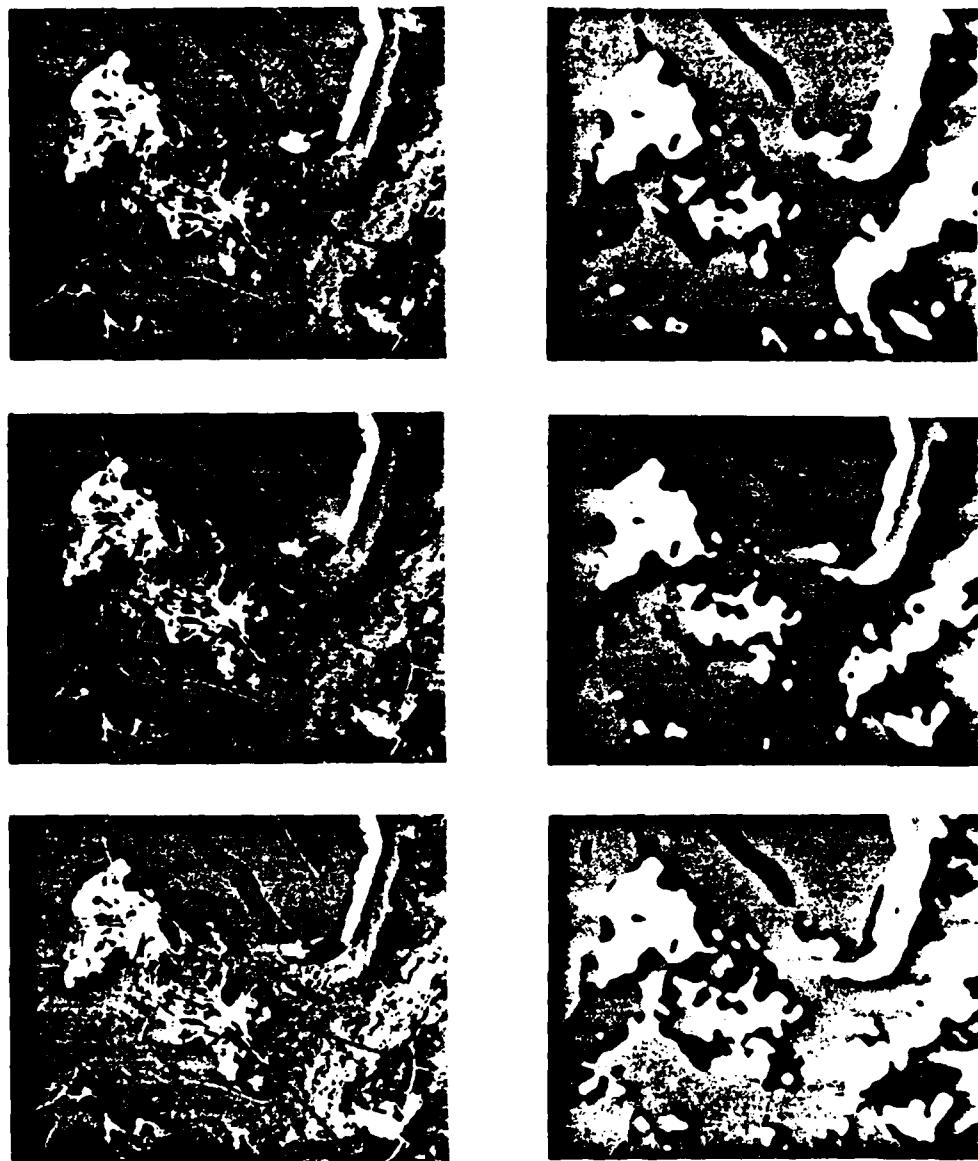


Figure 64. Vegetation Themes for Three Spectral Band Combinations:
Raw (Left), Smoothed (Right). Bands A, B, C Top to Bottom

classification using thermal data identifies the creek and river totally, with a few small false inclusions around the river where steep slopes and sun angle caused a forested area to have the same signature as water. All other vegetation classes were derived from the same data for the two cases. The results for these classes are the same, except that the signature for the forest class was modified in the second case to be more representative.

In this comparison, thermal infrared image data, as a supplement to green or panchromatic imagery, has considerable value. Using panchromatic photography only is presumed to be a desirable goal, but here it leads to some problems in water classification. The problem may not always exist, but further examination of typical image data is warranted.

E. Evaluation of Vegetation Boundary Extraction Results

1. Introduction

Two kinds of evaluation of vegetation/land cover analysis are presented here. First, for two of the subscenes in which interactive digital analysis was performed, manual analysis also was performed at USAETL using current techniques. The two areas involved are the Fort Belvoir/Woodbridge subscene, and a subscene from the Pennsylvania multispectral scanner flight data. Results from the interactive digital and the manual analyses are compared.

The second kind of evaluation pertains only to the large Pennsylvania scene. Here interactive digital analysis was performed using image data acquired at altitudes of 5000, 10,000 and 20,000 feet. Vegetation/land cover classification results are compared for the three altitudes.

2. Fort Belvoir/Woodbridge Subscene

The interactive digital and the manual analysis results are shown in Figure 65. There is good correlation between the two. If the unsmoothed, rather than the smoothed, digitized input image were to have been used in the interactive classification process, the correlation would have been higher, particularly at vegetation boundaries. Minor discrepancies between the two analyses, other than at vegetation boundaries, include:

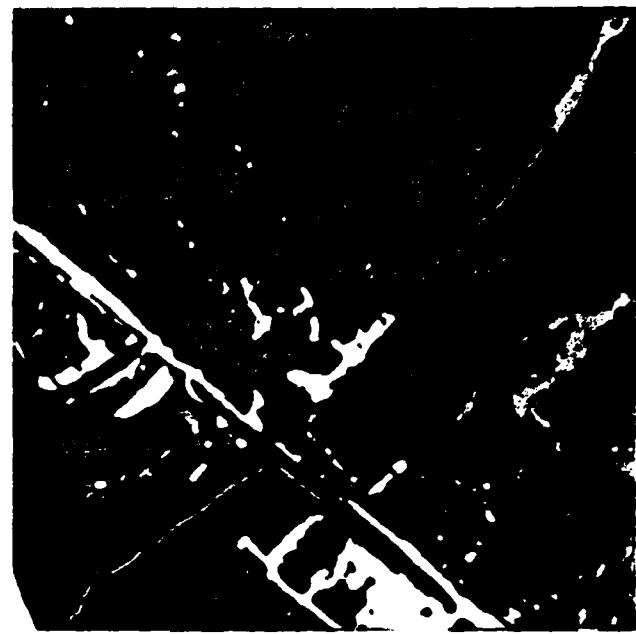


Figure 65. Comparison of Fort Belvoir/Woodbridge Vegetation Themes (Top) with Manual Analysis Results (Bottom)

- Some roadways and the railroad right-of-way are classified digitally as grassland due to the similarity of gray-levels in these areas and in grassland areas.
- Some narrow bare areas were not classified digitally. This was due to the use of the smoothed input image.
- Small areas of smooth grassland contained textural characteristics similar to water and were digitally classified as water.
- Most forest areas have been accurately classified digitally. However, some areas of thin forest are digitally classified as grassland.
- A few small areas of brush and small trees are digitally classified as marsh.
- Some areas which manual analysis identified as marsh are digitally classified as grassland.
- A few scratches on the aerial transparency apparently were picked up in the digitizing and resulted in small areas in the water being digitally classified as grassland.
- The extreme lower left portion of the digitally classified image identifies a bare and grassland area apparently missed in the manual analysis.

3. Pennsylvania Scene-Comparison with Manual Analysis

The full Pennsylvania scene involves a strip of airborne scanner data approximately seven miles long (for the 10,000-foot altitude flight). For comparison of digital and manual analyses, a portion of this scene, about two miles square, was examined. The digital analysis results used for the comparison are taken from the large scene analyses at three altitudes. The overall scene is quite complex and provides a very stringent test for the interactive digital processing procedure. In the subscene where comparisons are made, there are areas of thin stands of forest (due to cutting, or due to partially revegetated surface mines), and these create some difficult classification problems.

The digital and manual analyses map the subscene into four classes - forest, grassland, water and bare. Results are shown in Figure 66. Although the digital analysis examined both broadleaf and needleleaf forest, these two categories are lumped together for the comparison with manual analysis. Classification accuracy for the digital analysis, using the manual analysis results as the reference, can be summarized as follows:

Relative Accuracy of Digital Classification

Vegetation/Land

<u>Cover Class</u>	<u>5K Ft. Alt.</u>	<u>10K Ft. Alt.</u>	<u>20K Ft. Alt.</u>
Forest	Fair to Good	Fair	Poor
Grassland	Fair to Good	Fair	Poor
Water	Good	Good	Fair
Bare	Good	Good	Good

The areas of thin stands of forest have digital signatures similar to grassland, and the accuracy of the resulting digital classification for forest suffered primarily because of this. In the figure, digitally classified bare areas, derived from the 10,000-foot and 20,000-foot altitude data, do not exhibit high accuracy. This is a result of the theme smoothing process used. The unsmoothed themes for bare areas for the same two altitudes correlate very well with the manual analysis results. Thus, the required information exists in the data, and this is the basis for the "good" rating in the classification accuracy table. However, more efficient theme processing needs to be implemented. Using the 5000-foot altitude data, both the smoothed and the unsmoothed themes for the bare class correlate very favorably with the manual analysis.

Narrow themes, such as roads, need to be inserted into the smoothed themes. The feasibility of this has been demonstrated previously, but implementation of the procedure was not employed in the digital analyses which have been compared here with a manual analysis.

4. Pennsylvania Scene - Classification vs. Data Resolution

One purpose in digitally analyzing the Pennsylvania scene data was to investigate the effect of data resolution on classification accuracy. This

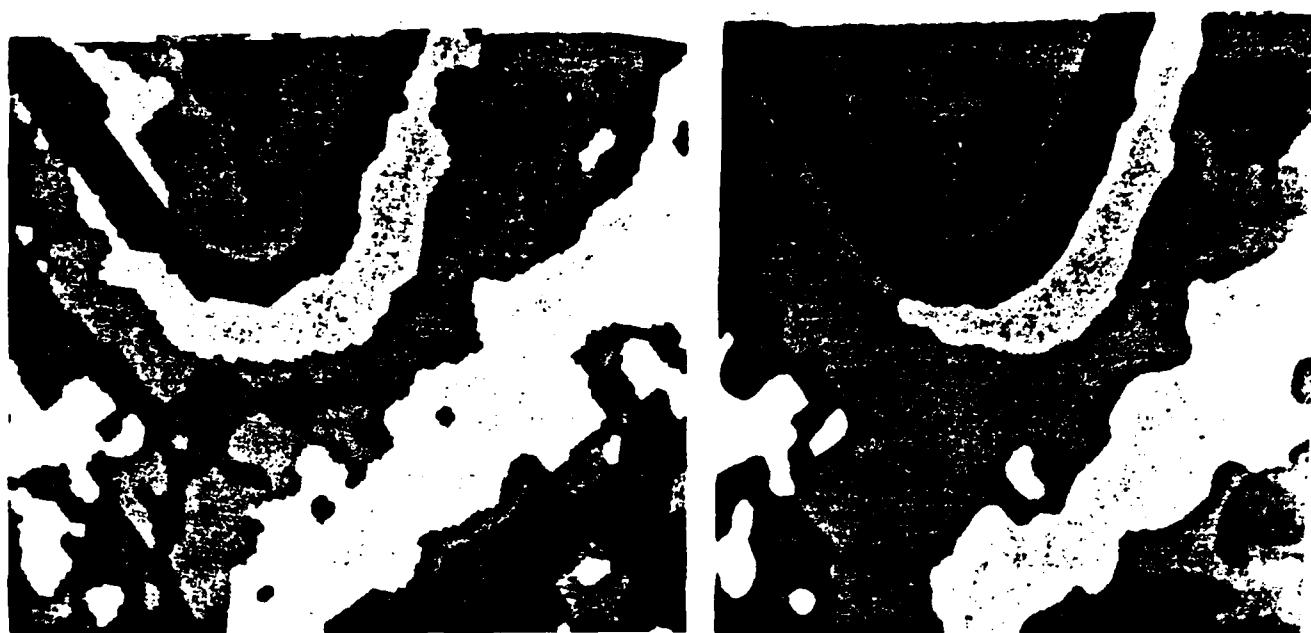


Figure 66. Comparison of Pennsylvania Vegetation Themes with Manual Analysis Results (Lower Right). (20,000, 10,000 and 5,000-Foot Altitude Themes at Upper Left, Upper Right, Lower Left.)

was possible by analyzing image data from the same scanner operating successively at three flight altitudes - 5000, 10,000 and 20,000 feet. The corresponding pixel linear dimensions for these data sets are approximately 10, 20 and 40 feet, respectively. An additional purpose in analyzing the Pennsylvania scene was the large diversity of scene content. In the lower half of the flight line (not included in the area which was used for the digital-manual analysis comparison) are large areas of agricultural land and grassland. Boundaries between fields present a texture effect which can be digitally misinterpreted (i.e., as forest) at some levels of resolution. The thin forest stands noted previously also present digital classification problems.

In the section just preceding, digital classification using three levels of data resolution (three flight altitudes) was compared to classification via manual analysis. In effect, this also amounted to an assessment of digital classification performance vs. data resolution. The results tend to indicate that 10-foot resolution will enable quite acceptable vegetation/land cover digital classification and boundary extraction for purposes of a 1:50,000 scale factor overlay. Data having 40-foot resolution appears to be inadequate for the same purpose. Potential for the 20-foot resolution data lies somewhere between these limits. While such data yield classification errors in some categories, it is not clear that the errors will lead to unacceptable factor overlays at 1:50,000 scale. This needs further investigation.

VI. CONCLUSIONS

A. Interactive, digital techniques have been developed for the extraction, from digitized panchromatic photography, of:

- A tree crown theme (a binary map in which single pixels indicate the location of individual tree crowns in a forest or in less densely wooded areas).
- A forest area theme
- A forest canopy theme

From these three themes it is possible to produce, in an automated operation, the following terrain vegetation data elements:

- Percent canopy closure
- Stems per hectare
- Crown diameter
- Stem diameter
- Stems per hectare per diameter class
- Stem spacing.

The techniques produce the best results with a spatial resolution in the input digital image of approximately 3 feet. At this resolution the interactive analysis is performed at any one time in regions of the scene approximately 1500 feet x 1500 feet in size (i.e., 500 x 500 pixels).

B. Interactive, digital techniques have been developed for the extraction of vegetation/land cover boundaries from digitized panchromatic photography, and from digital scanner data used to simulate the panchromatic photography. In some cases, particularly to resolve conflicts between water and grassland, the use of digital thermal image data is a necessary or desirable supplemental input to the process.

The techniques are most effective when the spatial resolution in the input digital image is in the range of 8 to 20 feet.

The extraction procedure is such that, after a moderate amount of interactive analysis, batch processing can be employed to extend the boundary extraction to relatively large areas (many square miles) quite rapidly and efficiently.

C. Results of vegetation element extraction via the interactive digital procedure have been compared to results obtained using existing manual procedures for two cases involving vegetation/land cover boundary extraction:

- Fort Belvoir/Woodbridge subscene (0.65 square mile)
 - Good correlation of results
- Pennsylvania subscene (4 to 5 square miles)
 - Fair to good correlation of results
 - This subscene is complex and presents some difficult analysis problems, perhaps of greater than average difficulty. In view of this, results are considered to be promising.

In both of the subscene comparisons, the interactive digital results contained several relatively small inaccuracies. Some of these are correctible with additional interactive analysis. Other inaccuracies may not warrant correction. This needs further evaluation in terms of the final product (i.e., factor overlay).

Interactive digital techniques for tree crown counting and for other forest-related element extraction have not been compared to the corresponding manual analysis. This should be done in a future effort.

The analysis time and the system complexity for the interactive digital extraction techniques have not been compared to those for manual analysis. This also should be done in a future effort. It should be pointed out that the interactive digital techniques were developed using a general purpose system - the General Electric Digital Image Analysis Laboratory (DIAL). Digital processing can be expected to be more efficient using a specially designed system, and larger scene areas will be accommodated more readily.

Procedures have been developed for distance, elevation and area measurements on the digital imagery. Further testing and evaluation is necessary in the future.

E. In the course of the study reported here, the need has become apparent for the development of the following improved techniques to be used in interactive digital terrain element extraction:

- Spatial filtering of theme (binary map) contiguous areas so as to remove isolated small groups of pixels and holes. Themes with considerable fine structure (due to shadows, gaps between trees in a forest, etc.) invariably are produced when digitally classifying imagery containing vegetation and most other land cover features. Such fine structure generally is not desired in the map products which are produced from the processing.
- Theme butting and region growing so as to compensate for gaps between vegetation/land cover themes produced in a digital classification process which is preceded by a digital smoothing operation on the input image data. The smoothing is essential for good classification, but gaps between themes becomes an undesired by-product.
- Geometric scaling and resolution changing in the digital image in a rapid, efficient manner. This need exists because several vegetation element extraction procedures involve passing a digital template or moving operator over the image (e.g., for tree crown or texture extraction), and the performance of this operation is scale sensitive.

F. As a supplement to the extraction technique development and imagery analysis which is reported here, additional applicable imagery (panchromatic photography, thermal infrared and radar imagery) should be analyzed in a future effort. This is necessary in order to:

- Test the new procedures in a greater diversity of scenes so that technical feasibility and credibility may be thoroughly established.
- Evaluate more thoroughly the utility of all three types of imagery, and the combinations of these three. In particular, radar imagery and sets of imagery have received only cursory evaluation at this time.

- Achieve results which are based more heavily on analysis of digitized aerial image transparencies rather than analysis of digital airborne scanner data (as has been partially necessary in the initial phase of the study).

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